Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-73

Gregory N. Katnik, Barry C. Bowen, Jill D. Lin

Technical Memorandum 111465 December 1995

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-73

Gregory N. Katnik, Barry C. Bowen, Jill D. Lin,
Vehicle Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space Center, Florida

Technical Memorandum 111465 December 1995

DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-73

20 October 1995

Prepared By:

Mario J. Bassignani
ET Handling/GSE Systems
NASA/KSC/TV-MSD-7

J. Bradley Davis
Photo/Optical Systems
NASA/KSC/TV-MSD-7

Jill D. Lin
Shuttle Ice/Debris Systems
NASA/KSC/TV-MSD-7

Barry C. Bowen
Infrared Scanning Systems
NASA/KSC/TV-MSD-7

Jorge E. Rivera
Mechanical/Structural Systems
NASA/KSC/TV-MSD-7

Robert F. Speece
Thermal Protection Systems
NASA/KSC/TV-MSD-7

Approved:

Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA/KSC/TV-MSD-7

James G. Tatum
Chief, ET/SRB Mech/TPS Systems
NASA/KSC/TV-MSD-7

TABLE OF CONTENTS

TABLE OF CONTENTS continued

TABLE OF FIGURES

TABLE OF PHOTOS

FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

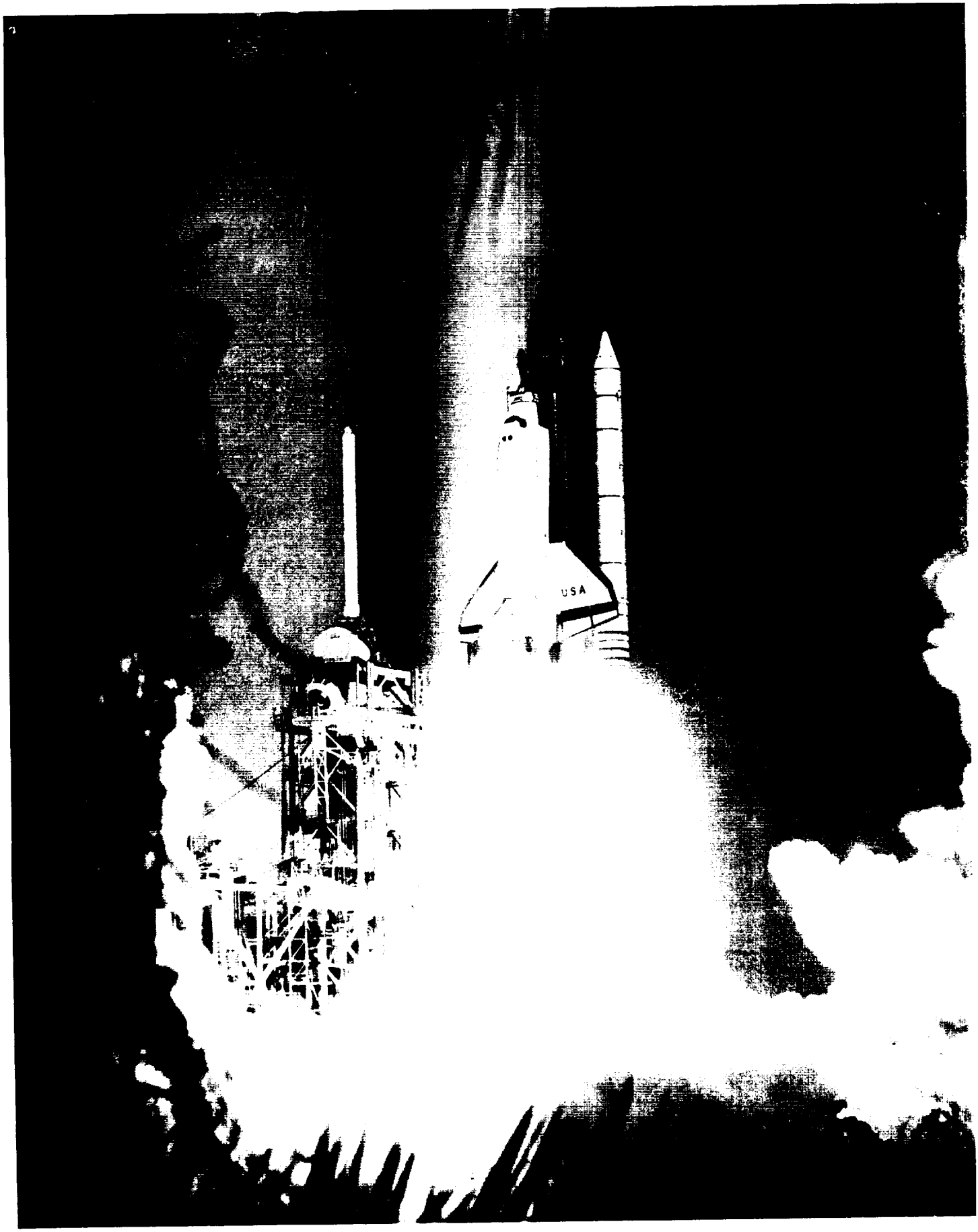


Photo 1 : Launch of Shuttle Mission STS-73

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 27 September 1995. The detailed walkdown of Pad 39B and MLP-3 also included the primary flight elements OV-102 Columbia (18th flight), ET-73 (LWT 66), and BI-075 SRB's. There were no significant vehicle or pad anomalies.

Damage to acreage TPS was detected on the LO2 tank and believed to have been caused by woodpeckers. Four cavities, which averaged 1-inch in diameter and 0.5-inches deep, were located on the LO2 tank. Icing analysis of these damage sites predicted frost, but no ice, during cryoload due to sufficient remaining foam thickness and expected warm ambient weather conditions. Trajectory analysis showed minimal threat to the Orbiter during ascent. The condition was accepted for flight without the need to repair the damage sites.

The launch of STS-73 was scrubbed at approximately T-3.5 hours due to an SSME #1 main fuel (hydrogen) valve leak. Loading of the External Tank had not reached topping and stable replenish. Drain was initiated without performing a Final Inspection. No significant vehicle damage was detected during the post drain inspection.

A second launch attempt was scrubbed 7 October 1995 at T-20 minutes due to a Main Events Controller (MEC) #1 core B failure. The only Orbiter anomaly detected during the Final Inspection consisted of green-tinted R2R and R2D RCS thruster covers indicating a small internal vapor leak. Frost, but no ice, had partially filled the bird-induced TPS damage sites on the LO2 tank. Post drain inspection of the vehicle revealed no anomalies with the exception of missing topcoat from the ET nose cone GOX vent seal footprint area.

The vehicle was cryoloaded for the third time on 15 October 1995. The only significant change from the previous cryoload consisted of three cracks (two 4-inches in length and one 1-inch in length) in the -Y ET/SRB cable tray forward surface TPS. The three-crack condition was assessed by the Debris Team and determined to be acceptable for flight.

The launch was scrubbed at T-5 minutes due to KSC launch and RTLS weather LCC violations. A post drain inspection revealed more topcoat was missing from the ET nose cone GOX vent seal footprint areas. A small divot in the aft dome NCFI just aft of the cryoflex panel closeout was correlated to a pre-rollout condition. No anomalies were observed on the Orbiter, SRB's, or MLP.

The vehicle was cryoloaded for the fourth time on 20 October 1995. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. As expected, there was no acreage ice or frost given the ambient weather conditions at this time of year. There were no protuberance icing conditions outside of the established data base. No new significant anomalies had appeared on the External Tank.

After the 09:53 a.m. (local) launch on 20 October 1995, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. Rockwell-Downey reported a 0.25g lateral acceleration at liftoff. However, there was no visual indication of a stud hang-up on any of the south holddown posts. All the T-0 umbilicals operated properly. A small amount of topcoat from the External Tank nose cone adhered to one GOX seal. Overall, damage to the launch pad was minimal.

A total of 117 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. SSME ignition appeared normal with the exception of Mach diamonds forming in a 2-3-1 sequence. This was caused by the Phase II/Block I mix of SSME's with slightly different startup times.

A stud hang-up occurred on holddown post #2. As the vehicle gained altitude and the stud became visible above the HDP shoe, aluminum from the wall of the stud hole was observed in the stud threads. Two semi-circular pieces of aluminum fell from the top area of the stud to the HDP shoe. One ordnance fragment fell from the DCS after the stud cleared the stud hole. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe approximately 2 inches before the stud cleared the SRB aft skirt foot. No stud hang-ups occurred on any of the other holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes with the exception of the HDP #2 event.

Orbiter umbilical camera films showed nominal separation of SRB's from the External Tank and normal separation of the ET from the Orbiter. The LO2 ET/ORB umbilical sustained TPS damage at the top and inboard forward corner. Pieces of loose foam from these damaged areas were wedged against the aft side of the crossbeam. Lightning contact strips across the forward part of the umbilical and at the 8 o'clock position were missing. Loss of lightning contact strips was the subject of a previous IFA.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. The number of MSA-2 debonds on both frustums was greater than average. Numerous pins and retainer clips were missing from both frustum severance rings. Strands of nylon fiber caught on adjacent clips indicated the damage was caused by parachute riser entanglement after splashdown. The aft skirt holddown post #2 stud hole was broached by the stud hang-up at liftoff.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing inspection of OV-102 was conducted 5 November 1995 on SLF runway 33 at the Kennedy Space Center. The Orbiter TPS sustained a total of 147 hits, of which 26 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger was greater than average.

The Orbiter lower surface sustained a total of 102 hits, of which 17 had a major dimension of 1-inch or larger. The largest lower surface tile damage site occurred approximately 10 feet forward of the RH MLG wheel well and measured 11.0 inches long by 3.8 inches wide by 0.8 inch maximum depth. The site showed significant signs of re-entry heating including interior glazing, slumping at the tile edge, and melting of the surface coating material.

Aerodynamic flow analyses performed at Rockwell-Downey showed debris sources/origins most likely to have caused this damage would have been located in the ET LO2 tank cable tray area. The LO2 feedline upper bellows, new-method bipod jack pad closeouts, and SRB nose cap ablator were much less likely debris source locations. However, review of ET/ORB umbilical camera films and on-orbit photography of the ET after separation from the Orbiter showed no anomalies that might have been the cause of the damage.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from the facility environment, SRB BSM exhaust, Orbiter RCS nozzle cover adhesive, Orbiter TPS, and paints/primers from various sources. These residual sampling data do not indicate a single source of damaging debris as all of the noted materials have previously been documented in post-landing sample reports. The residual sample data showed no debris trends when compared to previous mission data.

A total of six Post Launch Anomalies, but no In-Flight Anomalies (IFA's), were observed during the STS-73 mission assessment.

2.0 LAUNCH SCRUBS

2.1 SCRUB - SSME FUEL VALVE

2.1.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 27 September 1995 from 0930 to 1100 hours. The detailed walkdown of Pad 39B and MLP-3 also included the primary flight elements OV-102 Columbia (18th flight), ET-73 (LWT 66), and BI-075 SRB's. There were no significant vehicle anomalies. A leaking SRB sound suppression water trough adjacent to the LH SRB nozzle extension was replaced.

Damage to acreage TPS was detected on the LO2 tank and believed to have been caused by woodpeckers. The cavities, which averaged 1-inch in diameter and 0.5-inches deep, were located in three places on the -Y side at station Xt-690 (approximately) and one place on the +Y side near the EB fitting. Icing analysis of these damage sites predicted frost, but no ice, during cryoload due to sufficient remaining foam thickness and expected warm ambient weather conditions. Trajectory analysis showed minimal threat to the Orbiter during ascent. The condition was accepted for flight without the need to repair the damage sites.

The launch of STS-73 was scrubbed at approximately T-3.5 hours due to an SSME #1 main fuel (hydrogen) valve leak. Loading of the External Tank had not reached topping and stable replenish. Drain was initiated without performing a Final Inspection.

Photo 2 : ET-73 Pre-Launch Condition

Damage to acreage TPS was detected on the LO2 tank and believed to have been caused by woodpeckers. The cavities, which averaged 1-inch in diameter and 0.5-inches deep, were located in three places on the -Y side

2.1.2 POST DRAIN VEHICLE INSPECTION

Pad access was available soon after the External Tank was drained. The post drain inspection of the vehicle was performed at Pad-39B from 0750 to 0855 hours on 28 September 1995.

No anomalies, such as divots or cracks, were observed on the LO2 tank, intertank or LH2 tank acreage.

Inspection of the nose cone -Y side revealed an area of missing topcoat 1-inch long by 0.5-inches wide to the -Z side of the louver. No foam damage was observed. The nose cone +Y side was not accessible for inspection. An inspection of the vent hood seals revealed topcoat adhered to both seal interfaces. A subsequent, more detailed, inspection revealed three areas of missing topcoat from the northeast GOX vent seal footprint area and one area from the southwest foot print area. These areas were documented on IPR 073V-0216.

No ice, loose foam, or TPS cracks were visible in the LO2 feedline support brackets.

The bipod jack pad closeouts were intact and flush with adjacent LH2 tank-to-intertank flange closeout foam.

The crack in the -Y ET/SRB vertical strut cable tray forward surface TPS noted during cryoloading was not visible.

ET/ORB LO2 and LH2 umbilicals exhibited typical ice/frost formations. A small ice ball was present on the forward inboard corner of the LH2 ET/ORB umbilical 17-inch disconnect actuator access port closeout.

Frost was visible in the cavities of two TPS (woodpecker) damage sites on the LO2 tank -Y/-Z quadrant. The small damaged area in the -Y/+Z quadrant exhibited no ice or frost. The damaged areas had previously been documented on PR ET-73-TS-022.

No anomalies were observed on the Orbiter, Solid Rocker Boosters, or MLP.

No significant vehicle damage was observed during the post drain inspection.

2.2 SCRUB - MAIN EVENTS CONTROLLER

2.2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 6 October 1995. There were no vehicle or significant facility anomalies. A piece of emery cloth laying on the LH SRB ETA ring near the EB-7 fitting could not be retrieved prior to the launch attempt.

2.2.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 7 October 1995 from 0420 to 0610 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken during the second cryoload. As expected, there was no acreage ice or frost given the ambient weather conditions at this time of year. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to scan the vehicle for unusual temperature gradients, particularly those areas not visible from remote fixed scanners, and to obtain a random sampling of vehicle surface temperature measurements to thermally characterize the vehicle.

2.2.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R2R and R2D RCS thruster covers were tinted green indicating a small internal vapor leak. Typical ice/frost accumulations and condensate were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

2.2.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the portable STI radiometer averaged 85 degrees Fahrenheit. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by THIO was 81 degrees F, which was within the required range of 44-86 degrees F.

2.2.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank. Two of the three bird-induced acreage CPR damage sites on the -Y/-Z side of the LO2 tank were partially filled with frost. The third damage site in the -Y/+Z quadrant exhibited no ice or frost. A fourth damage site, located in the +Y/+Z quadrant, was inaccessible for inspection.

The intertank acreage exhibited no TPS anomalies.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost accumulations, were present on the acreage.

There were no anomalies on the new-method bipod jack pad closeouts. A crack, 6-inches long by 1/4-inch wide, was present in the -Y ET/SRB cable tray forward surface TPS. The presence of the crack was acceptable for flight per the NSTS-08303 criteria.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister and plate gap purge vents. Ice/frost had formed on the aft pyro canister closeout bondline, the LH2 feedline-to-umbilical interface 6 o'clock position, and the 17-inch disconnect actuator access port closeout. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and drain.

2.2.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement). The piece of emery cloth previously laying on the LH SRB ETA ring had fallen into one of the sound suppression water troughs.

Photo 3 : ET/ORB LH2 Umbilical - Second Cryoload

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and drain.

2.2.3 POST DRAIN VEHICLE INSPECTION

The launch of STS-73 was scrubbed at T-20 minutes due to a Main Events Controller (MEC) #1 core B failure. The post drain inspection of the vehicle was performed at Pad 39B from 1445 to 1600 hours on 7 October 1995.

No anomalies were observed on the LO2 tank, intertank or LH2 tank acreage.

A small frost spot was visible in the cavity of the top bird-induced hole on the LO2 tank -Y/-Z quadrant. The lower hole in that same quadrant, along with the small damaged area in the -Y/+Z quadrant, exhibited no ice or frost. The damaged areas had previously been documented on PR ET-73-TS-022. The small damage site in the +Y/+Z quadrant was not accessible for inspection.

Although ET nose cone topcoat was missing from the southwest GOX seal footprint area, no TPS was damaged. The +Y side was not accessible for inspection. Topcoat adhered to both GOX vent seal interface surfaces. A small piece of foam (3/8-inch by 1/2-inch) also adhered to the +Y seal. There was no evidence of TPS erosion due to fretting or blowby.

Ice in the LO2 feedline support brackets had melted. Although crushed foam and SLA damage was suspected in the LO2 feedline Xt-1623 bracket, more detailed hands-on inspection revealed no anomalies.

The bipod jack pad closeouts were intact and flush with adjacent LH2 tank-to-intertank flange closeout foam.

The crack in the -Y ET/SRB vertical strut cable tray forward surface TPS, detected during cryoload, was still visible but appeared to have closed somewhat.

Ice/frost formations were still present on the ET/ORB LO2 and LH2 umbilicals. The LH2 umbilical 17-inch valve actuator access hole TPS closeout exhibited a large frost spot at the forward corner. Ice was visible in both LH2 feedline bellows as well as in the recirculation line bellows and the -Z burst disk.

No anomalies were observed on the Orbiter, Solid Rocket Boosters, or Mobile Launcher Platform.

No significant vehicle damage was observed during the post drain inspection.

Photo 4 : Missing Topcoat from Footprint Area

Although ET nose cone topcoat was missing from the southwest GOX seal footprint area, no TPS was damaged. There was no evidence of TPS erosion due to fretting or blowby

Photo 5 : Topcoat Adhered to GOX Vent Seals

Topcoat adhered to both GOX vent seal interfaces.
A small piece of foam (3/8-inch by 1/2-inch) also adhered to the +Y seal.

2.3 SCRUB - LAUNCH SITE WEATHER

2.3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 14 October 1995. There were no significant vehicle or facility anomalies.

2.3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 15 October 1995 from 0420 to 0600 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken during the third cryoload. As expected, there was no acreage ice or frost given the ambient weather conditions at this time of year. The acreage was wet from rain. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to scan the vehicle for unusual temperature gradients, particularly those areas not visible from remote fixed scanners, and to obtain a random sampling of vehicle surface temperature measurements to thermally characterize the vehicle.

2.3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R2R RCS thruster cover was tinted green indicating a small internal vapor leak. Typical ice/frost accumulations and condensate were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

2.3.2.2 SOLID ROCKET BOOSTERS

The predicted Propellant Mean Bulk Temperature (PMBT) supplied by THIO was 81 degrees F, which was within the required range of 44-86 degrees F.

2.3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The acreage on the LO2 tank, intertank, and LH2 tank was wet from light rain. There were no new TPS anomalies. The three bird-induced TPS damage sites on the LO2 tank -Y side exhibited no ice or frost. A fourth damage site, located in the +Y/+Z quadrant, was inaccessible for inspection. There were no anomalies on the new-method bipod jack pad closeouts.

Three cracks (two 4-inches in length and one 1-inch in length) in the -Y ET/SRB cable tray forward surface TPS were roughly in line. The three-crack condition was assessed by the Debris Team and determined to be acceptable for flight.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and drain.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of three OTV recorded items.

2.3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement).

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals.

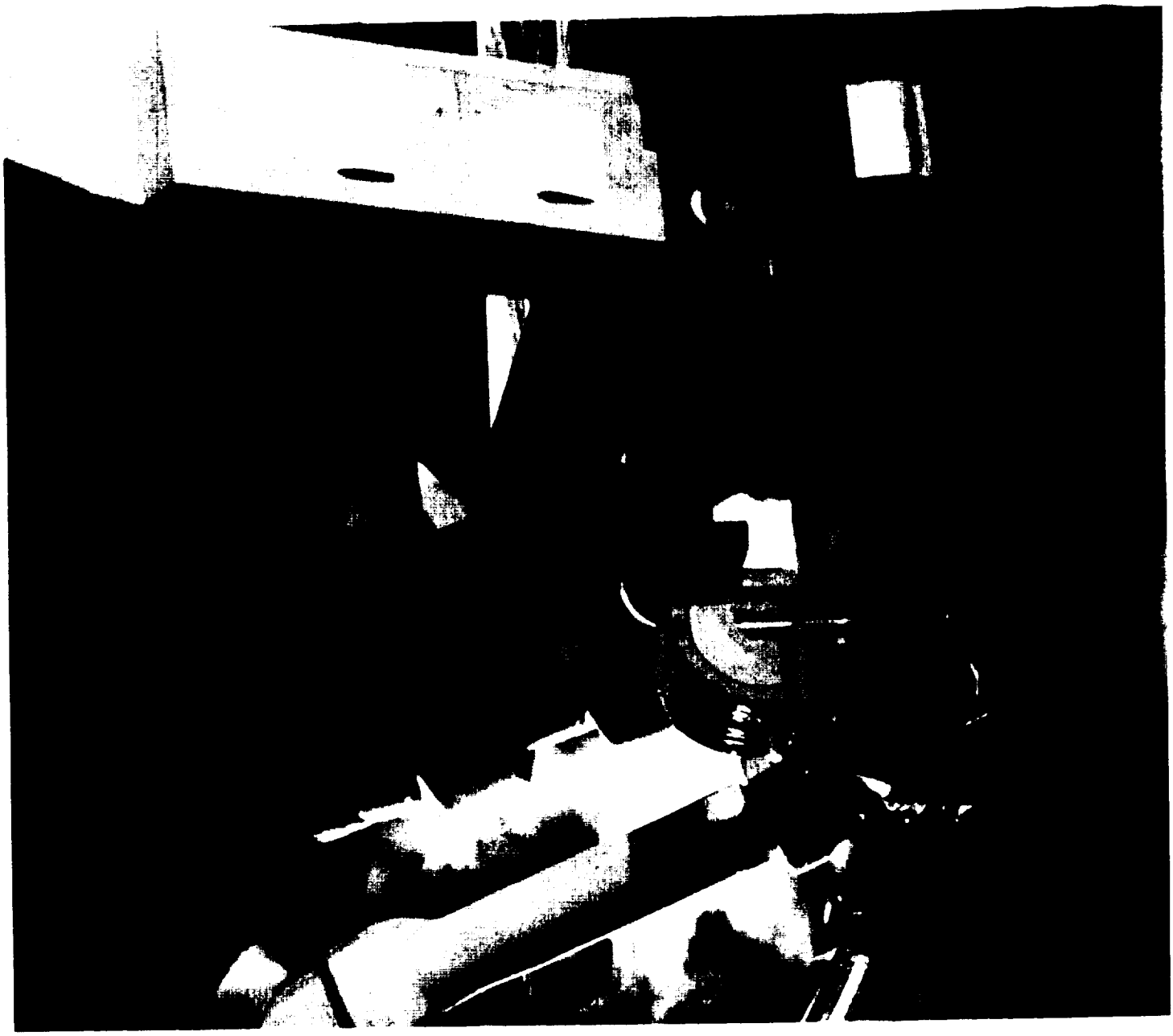


Photo 6 : ET/ORB LH2 Umbilical - Third Cryoload

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and drain.

2.3.3 POST DRAIN VEHICLE INSPECTION

The launch of STS-73 was scrubbed at T-5 minutes due to KSC launch and RTLS weather LCC violations. The post drain inspection of the vehicle was performed at Pad 39B from 1805 to 1905 hours on 15 October 1995.

No anomalies were observed on the LO2 tank, intertank or LH2 tank acreage. A divot (1.5 inches long by 0.75 inches wide by 0.5 inches deep) in the aft dome NCFI at approximately Xt-2086 on the -Z side just aft of the cryoflex panel closeout was correlated to a pre-rollout condition.

A small frost spot was visible in the cavity of the top bird hole on the LO2 tank -Y/-Z quadrant. The lower -Y/-Z hole exhibited no ice/frost. The small damaged area in the -Y/+Z quadrant also had no ice/frost. The damaged areas had previously been documented on PR ET-73-TS-022. The +Y hole was not accessible for inspection.

Although ET nose cone topcoat was missing from the -Y side footprint area, TPS damage appeared to be superficial. The +Y side was not accessible for inspection. The -Y footprint had 3 areas of missing topcoat. Two of these areas were aft of the vent louver and exposed foam, measuring 20 square inches and 7 square inches, respectively. A third area (+Z side of the vent louver) exposed SLA and measured almost 1 square inch in size. There was evidence of debonded topcoat along the +Z side of the -Y louver. Topcoat adhered to both GOX vent seal interfaces. Three areas of topcoat adhered to the northeast seal. Two of these areas originated from an area of foam substrate and measured 14 and 7 square inches, respectively. One area was from SLA substrate and measured 9 square inches. The was no evidence of TPS erosion due to fretting or blowby.

Ice in the LO2 feedline support brackets at Xt-1377 and Xt-1871 had not melted. No damage to the LO2 feedline or bracket TPS was visible.

The bipod jack pad closeouts were intact and flush with adjacent LH2 tank-to-intertank flange closeout foam.

The crack in the -Y ET/SRB vertical strut cable tray forward surface TPS, detected during cryoload, was still visible but appeared to have closed somewhat.

Typical ice/frost formations remained on the ET/ORB LO2 and LH2 umbilicals. The LH2 umbilical 17-inch valve actuator access hole TPS closeout exhibited a large frost spot at the forward corner. Ice was present in both LH2 feedline bellows and recirculation line -Z bellows.

Ice was visible in the gap between the aft fairing and the cable tray on both sides of the ET.

No anomalies were observed on the Orbiter, Solid Rocket Boosters, or Mobile Launcher Platform. No significant vehicle damage was observed during the post drain inspection.

3.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 27 September 1995 at 0830 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC Shuttle Ice/Debris Systems
J. Lin	NASA - KSC Shuttle Ice/Debris Systems
B. Davis	NASA - KSC Digital Imaging Systems
R. Speece	NASA - KSC Lead, Thermal Protection Systems
B. Bowen	NASA - KSC Infrared Scanning Systems
J. Rivera	NASA - KSC Lead, ET Mechanisms/Structures
M. Bassignani	NASA - KSC ET Mechanisms, Structures
M. Valdivia	LMSO - SPC Supervisor, ET/SRB Mechanical Systems
R. Seale	LMSO - SPC ET Mechanical Systems
J. Blue	LMSO - SPC ET Mechanical Systems
W. Richards	LMSO - SPC ET Mechanical Systems
M. Wollam	LMSO - SPC ET Mechanical Systems
G. Fales	LMSO - SPC ET Mechanical Systems
Z. Byrns	NASA - KSC Level II Integration
K. Mayer	Rockwell LSS Systems Integration
S. Reynolds	Rockwell LSS Systems Integration
M. Nowling	THIO - LSS SRM Processing
S. Otto	LMSO - LSS ET Processing
D. Maxwell	LMSO - SPC Safety

4.0 LAUNCH

STS-73 was launched at 20:13:53:00 GMT (9:53 a.m. local) on 20 October 1995.

4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 19 October 1995. There were no significant vehicle or facility anomalies.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 20 October 1995 from 0410 to 0550 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken during the fourth cryoload. As expected, there was no acreage ice or frost given the ambient weather conditions at this time of year. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to scan the vehicle for unusual temperature gradients, particularly those areas not visible from remote fixed scanners, and to obtain a random sampling of vehicle surface temperature measurements to thermally characterize the vehicle.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R2R RCS thruster cover was tinted green indicating a small internal vapor leak. Typical ice/frost accumulations and condensate were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

4.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the fixed STI radiometer were averaging 78-80 degrees F. Temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 77-82 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by THIO was 79 degrees F, which was within the required range of 44-86 degrees F.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank. There were no TPS anomalies. The three bird-induced TPS damage sites on the LO2 tank -Y side were partially filled with frost. The fourth damage site on the +Y side of the LO2 tank was not accessible for inspection.

The intertank acreage exhibited no TPS anomalies.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost accumulation, was present on the acreage.

There were no anomalies on the new-method bipod jack pad closeouts. The three-crack condition in the -Y ET/SRB cable tray forward surface TPS had not changed and was acceptable for flight per the Debris Team assessment and the NSTS-08303 criteria. Small ice/frost spots that typically appear during repeated cryoloadings were visible in five places on the -Y bipod spindle housing closeout, the -Y longeron closeout, and the aft dome apex.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. Ice/frost had formed on the aft pyro canister closeout bondline and on the forward corner of the 17-inch flapper valve actuator access port closeout. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of two OTV recorded items.

4.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement). Puddles of antifreeze were found on the MLP deck west of the LH SRB.

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals.

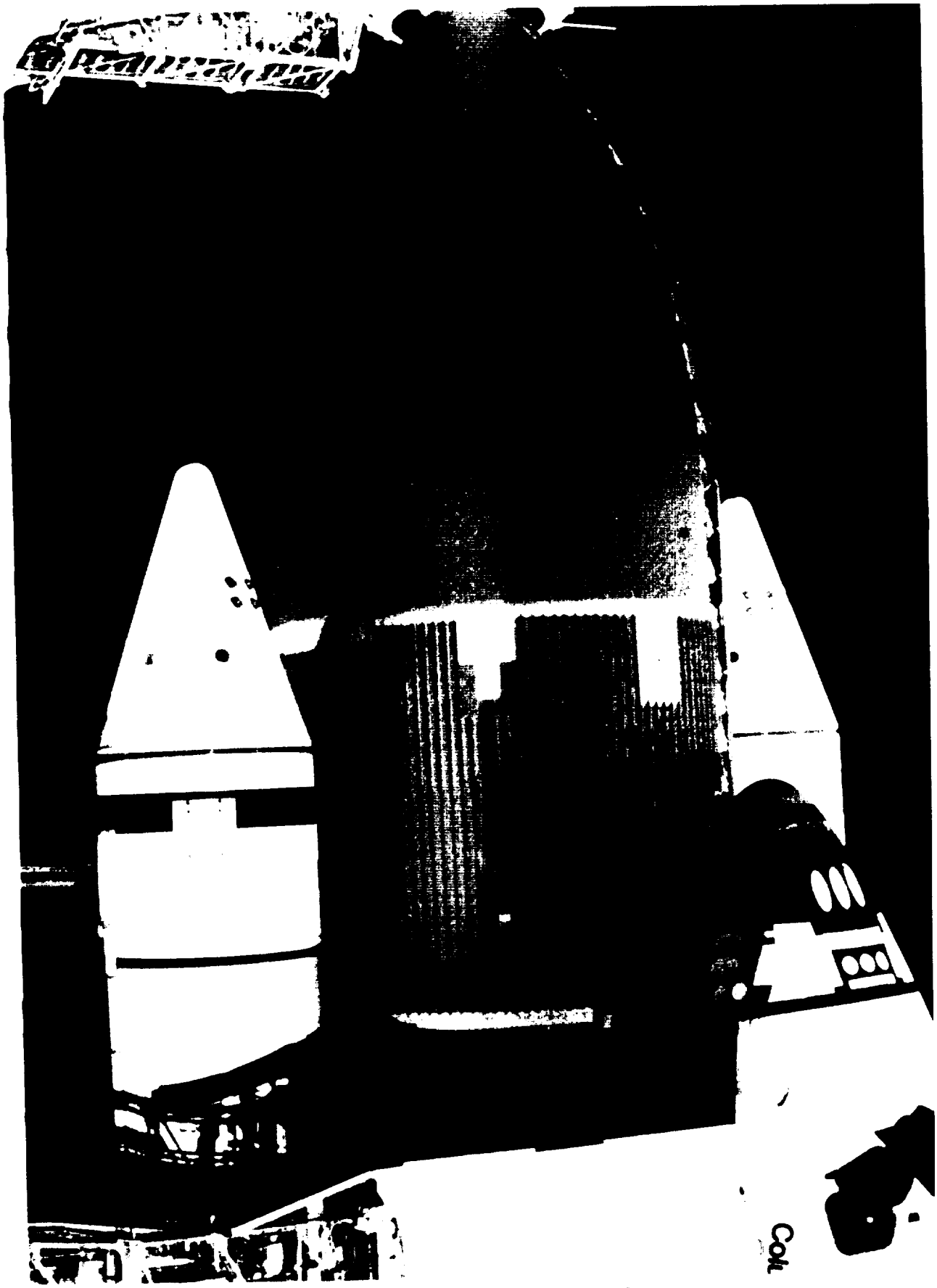


Photo 7 : ET-73 Cryoloaded for Launch

There was no acreage ice or frost given the ambient weather conditions at this time of year. There were no protuberance icing conditions outside of the established data base.

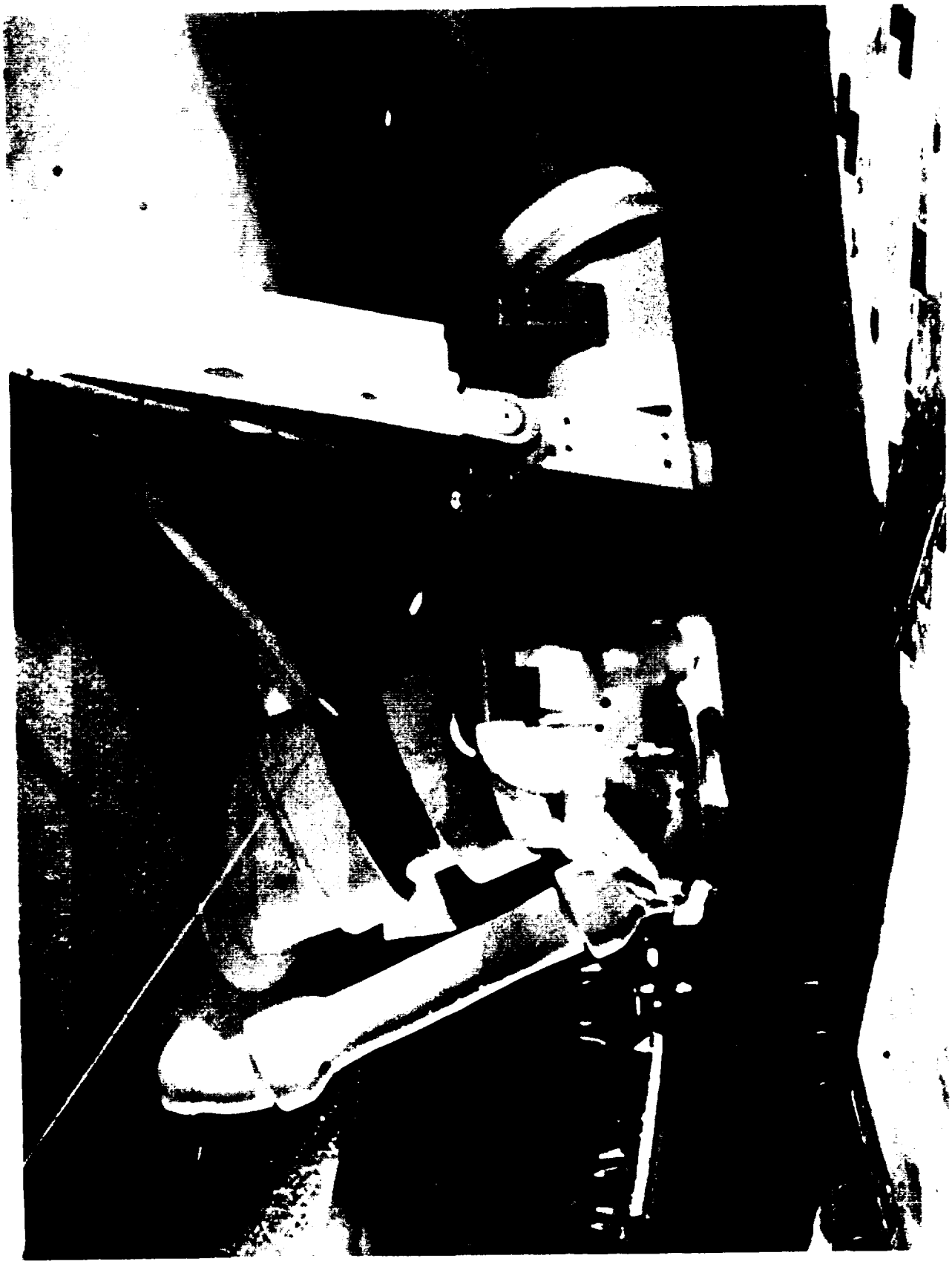


Photo 8 : ET/ORB LH2 Umbilical

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

5.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS, RSS, and Pad B crawlerway/west acreage was conducted on 20 October 1995 from Launch + 1 to 3 hours. The pad acreage east side and SRB flame trench were not accessible for inspection due to an facility LH2 leak and LO2 boiloff.

No flight hardware or TPS materials were found.

South SRB HDP erosion was typical. All south HDP shoe EPON shim material was intact. Rockwell-Downey reported a 0.25g lateral acceleration at liftoff. However, there was no visual indication of a stud hang-up on any of the south holddown posts. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was typical. Minor damage to the SRB aft skirt purge lines and T-0 umbilicals was similar to previous launches.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA), and GOX vent hood appeared undamaged. One small area of topcoat, approximately 3/8-inch diameter, from the External Tank nose cone adhered to the outboard surface of the southwest GOX seal.

The GH2 vent line had no loose cables (static retract lanyard), and appeared to have latched properly with no rebound. The GUCP legs and crossbeam showed no obvious signs of contact by the static retract lanyard. The vent line was latched on the sixth tooth of the latching mechanism. The RSS cable had disconnected properly.

Typical pad damage included:

Cable tray cover on the FSS 195 foot level southeast corner grating

A piece of grating dangled from the hammerhead crane

4-foot long by 8-inch wide piece of sheet metal flashing lay in the south flame trench

Overall, damage to the pad appeared minimal.

Post launch pad inspection anomalies are listed in Section 10.

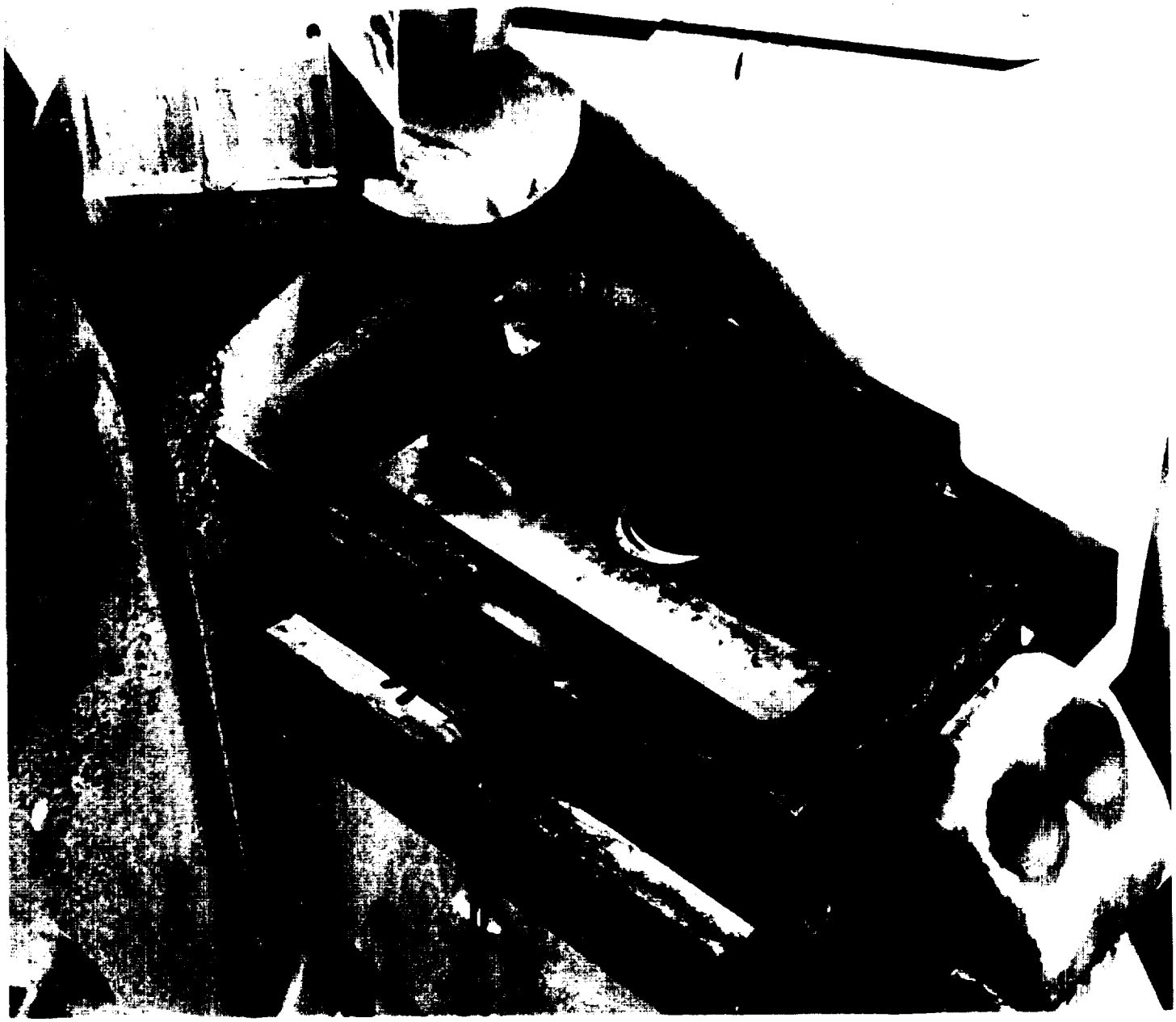


Photo 9 : Aft Skirt Shoe Shim

Although the aft skirt shoe shim material was intact, the new material, which is somewhat darker than the material used prior to BIO74, exhibited a bubbled appearance after launch.

6.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review. Post flight anomalies are listed in Section 10.

6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 100 films and videos, which included thirty-nine 16mm films, nineteen 35mm films, three 70mm films, and thirty-eight videos, were reviewed starting on launch day.

Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster occurred during engine start-up. The motion was similar to that observed on previous launches (E-76).

SSME ignition appeared normal with the exception of Mach diamonds forming in a 2-3-1 sequence. This was caused by the Phase II/Block I mix of SSME's with slightly different startup times. Free burning hydrogen drifted upward to the base heat shield and OMS pods during start-up (OTV 151, 170, 171; E-63, -76).

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice contacted the LH2 umbilical cavity sill and were deflected outward. No tile damage was visible (OTV 109).

One piece of ice fell aft from the LO2 feedline upper bellows without contacting flight hardware (E-79).

Small pieces of tile surface coating material were lost from 2 places on the base heat shield outboard of SSME #3 (E-17), 3 places on the base of the RH RCS stinger (E-17), 3 places on the base heat shield outboard of SSME #2 (E-18), and 2 places on the OMS pod base heat shield (E-18).

The SRB ignition shock wave caused water vapor to condense in the atmosphere above the SRB flame trench momentarily after T-0. A secondary vapor cloud formed briefly as well as the vehicle gained altitude and the SRB exhaust shock wave bounced off the MLP deck (OTV 141, 148, TV-4B, TV-5).

A stud hang-up occurred on holddown post #2. As the vehicle gained altitude and the stud became visible above the HDP shoe, aluminum from the wall of the stud hole was observed in the stud threads. Two semi-circular pieces of aluminum fell from the top area of the stud to the HDP shoe. One ordnance fragment fell from the DCS after the stud cleared the stud hole. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe approximately 2 inches before the stud cleared the SRB aft skirt foot (E-8).

No stud hang-ups occurred on any of the other holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes with the exception of the HDP #2 event.

A rectangular piece of cardboard appeared in the field of view between HDP #7 and #8 at 13:53:00.643 GMT (E-11, -14). Three 3-inch by 1-inch strips of material (sound suppression water trough parts tags) and an almost square object (believed to be a piece of sandpaper inadvertently left on the LH SRB -Z ETA ring and later blown into a sound suppression water trough) appeared between holddown posts #7 and #8 after T-0. These objects were pulled into the SRB exhaust hole by SRB plume aspiration (E-11, -14, -16)

Debris particles, most likely pieces of SRB throat plug material, and numerous pieces of shredded SRB sound suppression water trough material, were ejected out of the SRB exhaust holes and passed by the SRB aft skirts moving away from the vehicle shortly after T-0.

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150, 170, 171).

GUCP disconnect from the ET was nominal. No damaged foam was visible in the area after retraction. (OTV 104; E-33). GH2 vent line retraction and latch were normal. Slack in the static retract lanyard was minimal (E-41, -50, -60).

Movement of the GOX vent hood in the SRB plume after the vehicle cleared the tower appeared to be similar to previous launches and resulted in no unusual damage (E-62).

Numerous, bright flashes occurred in the SSME plume during and after the roll maneuver. This phenomenon has been observed on previous launches (E-52, -57).

Three pieces of ET/ORB purge barrier material fell aft during and after the roll maneuver (E-207).

Four pieces of light-colored debris, most likely chunks of instafoam from the SRB aft skirts, fell out of the SRB plume after the roll maneuver (E-59).

A considerable portion of the long range tracking coverage was obscured by clouds.

Three flares occurred in the SSME plume during ascent (TV-21B; E-222).

Body flap movement (amplitude and frequency) appeared similar to previous flights (E-207, -213)

Localized flow condensation collars formed on various parts of the vehicle at altitude as expected for the warm, humid, ambient weather conditions (E-207, -213, -220; TV-4B, TV-5, TV-21B).

ET aft dome charring and SRB separation appeared nominal. (E-207, -212).

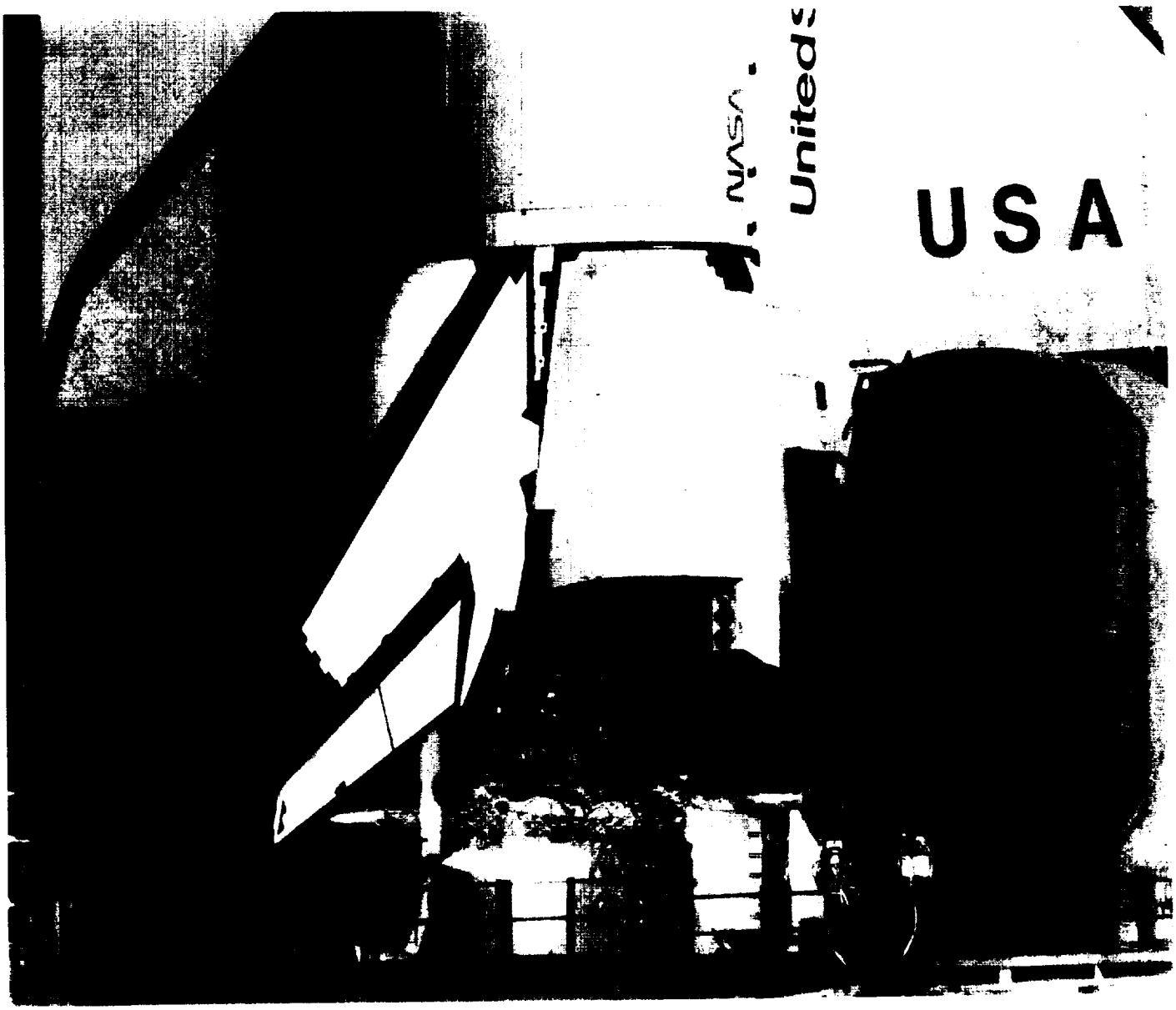


Photo 10: SSME Mach Diamond Formation

SSME ignition appeared normal with the exception of Mach diamonds forming in a 2-3-1 sequence. This was caused by the Phase II/Block I mix of SSME's with slightly different startup times.

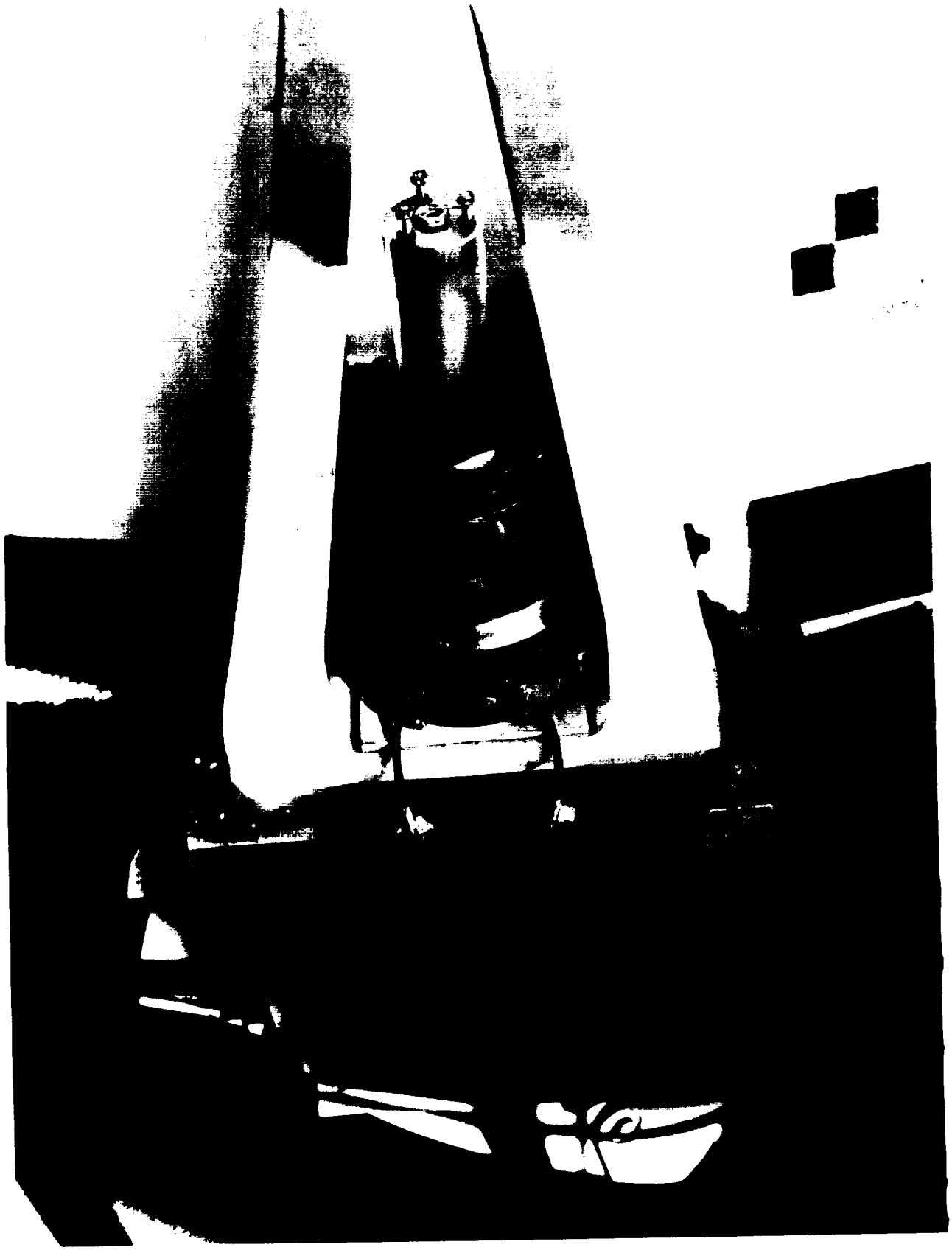


Photo 11: Holddown Post #2 Configuration

Pre-Launch configuration of the holddown post with the stud hang-up

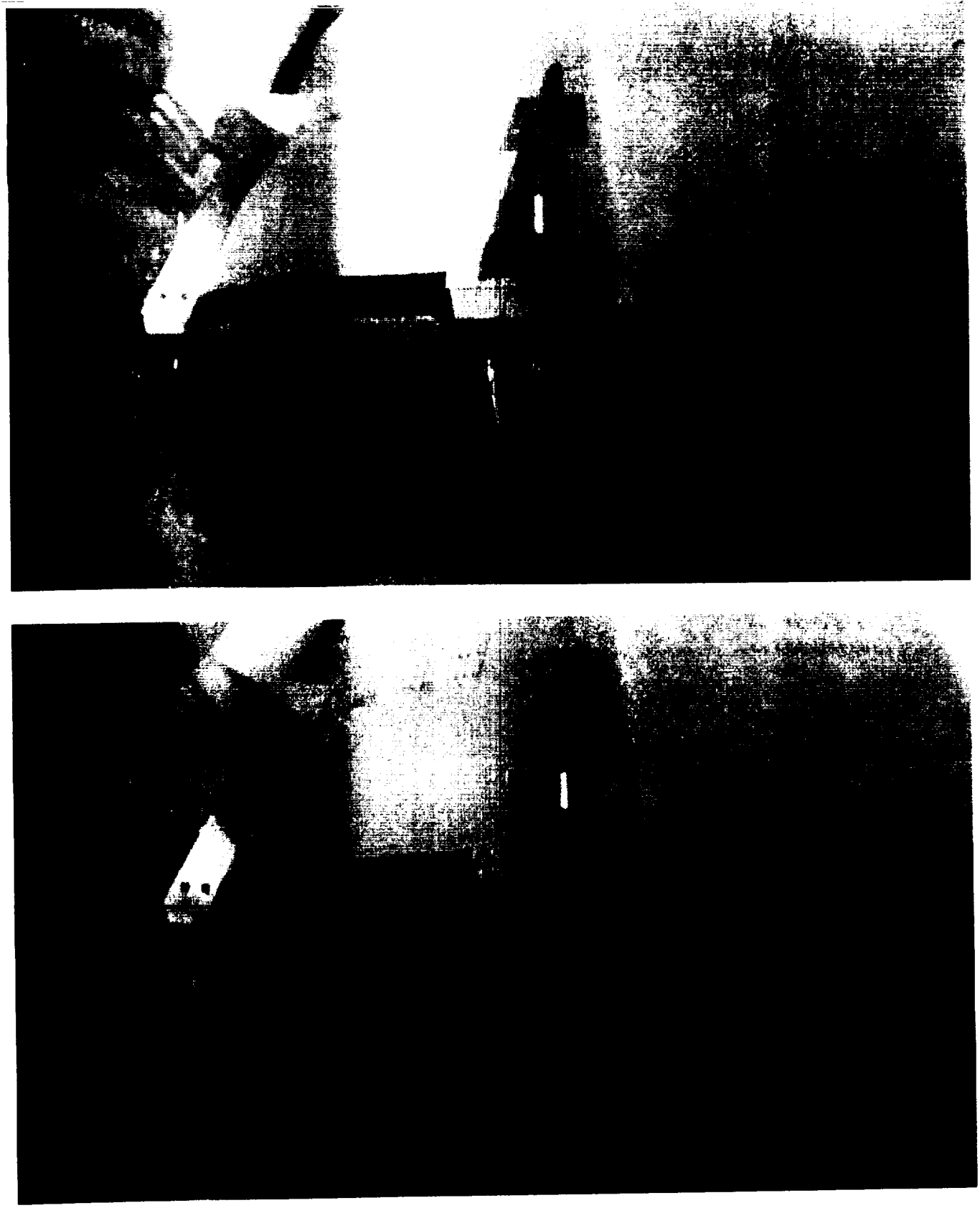


Photo 12: Holddown Post #2 Stud Hang-Up

A stud hang-up occurred on holddown post #2. As the vehicle gained altitude and the stud became visible above the HDP shoe, aluminum from the wall of the stud hole could be seen in the stud threads. Two semi-circular pieces of aluminum fell from the top area of the stud to the HDP shoe. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe approximately 2 inches before the stud cleared the SRB aft skirt foot.

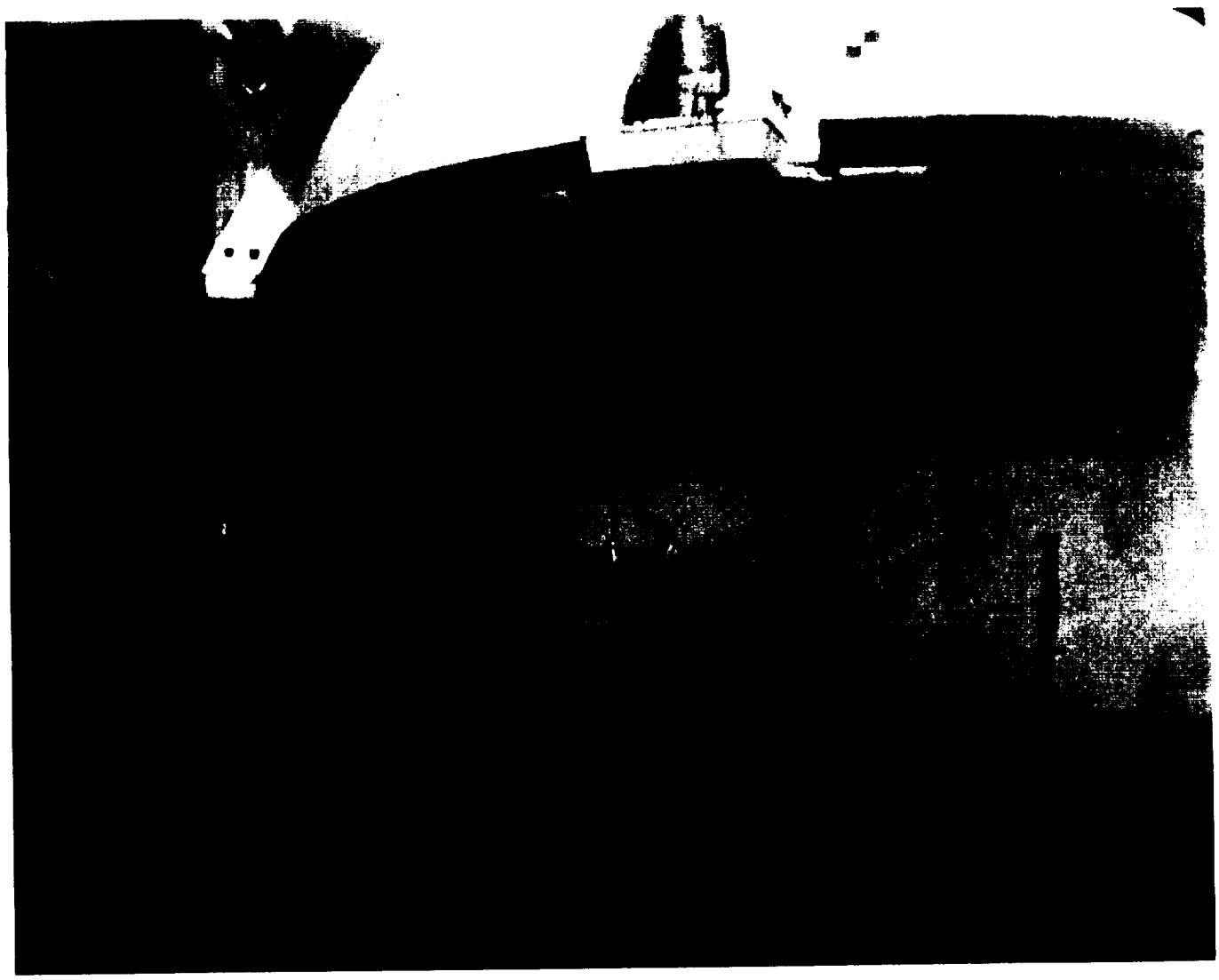


Photo 13: Ordnance Debris Fell from Stud Hole

One ordnance fragment fell from the Debris Containment System (DCS) after the stud cleared the stud hole

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-102 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Data was obtained from all three cameras along with hand held photography by the flight crew.

No vehicle damage or lost flight hardware was observed that would have been a safety of flight concern.

SRB separation from the External Tank was nominal.

ET-73 separation from the Orbiter was nominal.

There were no ET intertank acreage or LH2 tank-to-intertank flange closeout divots. Both new-method bipod jack pad closeouts appeared to be intact. No obvious cause for the large lower surface tile damage site on the Orbiter was observed. An aerodynamic flow analysis performed at Rockwell-Downey concluded the debris source for this damage site was most likely the LO2 tank ogive/cable tray area. TPS/ice debris originating from the ET bipod area, LO2 feedline (upper bellows), or SRB nose cap were considered to be much less likely sources. However, no anomalies in all of these areas were detected in the umbilical films. A trail of 5 shallow impact sites on the ET LH2 tank acreage CPR outboard of the LH2 cable tray was located at XT-1850. A common event may have caused this damage as well as the tile impact on the Orbiter lower surface.

An 8-inch by 6-inch by 1-inch TPS closeout over the -Y longeron-to-vertical strut/cable tray attach point popped off the External Tank and moved in the -Y direction shortly after ET separation (10mm film, frame 6178). A large void, but no substrate or primer, was visible afterwards. A cryopumped void in the closeout, along with possible cracks in the TPS closeout induced by flexing of the strut during separation, is believed to be the cause of this event.

A divot on the +Y thrust strut flange closeout exposed substrate/primer.

The LH2 ET/ORB umbilical appeared to be in good condition with little or no TPS damage. Foam was missing or eroded from the horizontal (clamshell) section of the cable tray and the aft surface of the -Y vertical strut. A small, reflective, rectangular object appeared from an area behind the umbilical cable tray clamshell and fell aft just after separation (5mm film). The origin of the object could not be determined.

The LO2 ET/ORB umbilical sustained TPS damage at the top and inboard forward corner. Pieces of loose foam from these damaged areas were wedged against the aft side of the crossbeam. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. Lightning contact strips across the forward part of the umbilical and at the 8 o'clock position were missing. Loss of lightning contact strips was the subject of a previous IFA. A thin, metallic-foil object, believed to be the small lightning contact strip from the 8 o'clock position, drifted across the camera field of view after ET sep (frame 8289).

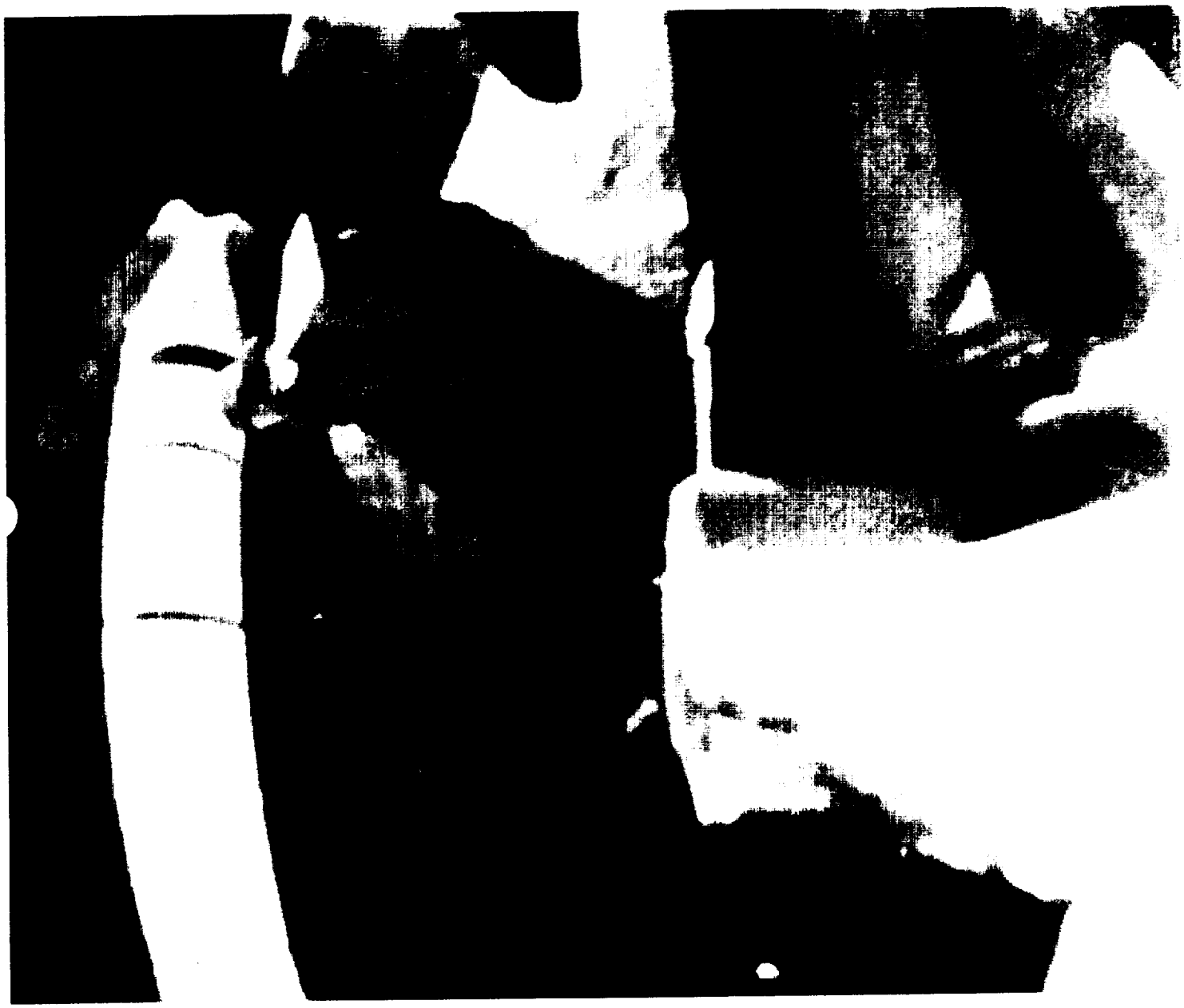


Photo 14: SRB Separation from External Tank

SRB separation from the External Tank was nominal Foam was missing or eroded from the horizontal (clamshell) section of the cable tray and the aft surface of the -Y vertical strut - a common occurrence

Photo 15: Vertical Strut/Cable Tray Attach Point Closeout

An 8-inch by 6-inch by 1-inch TPS closeout over the -Y longeron-to-vertical strut/cable tray attach point popped off the External Tank and moved in the -Y direction shortly after ET separation. A large void, but no substrate or primer, was visible afterwards. A cryopumped void in the closeout, along with possible cracks in the TPS closeout induced by flexing of the strut during separation, is believed to be the cause of this event.

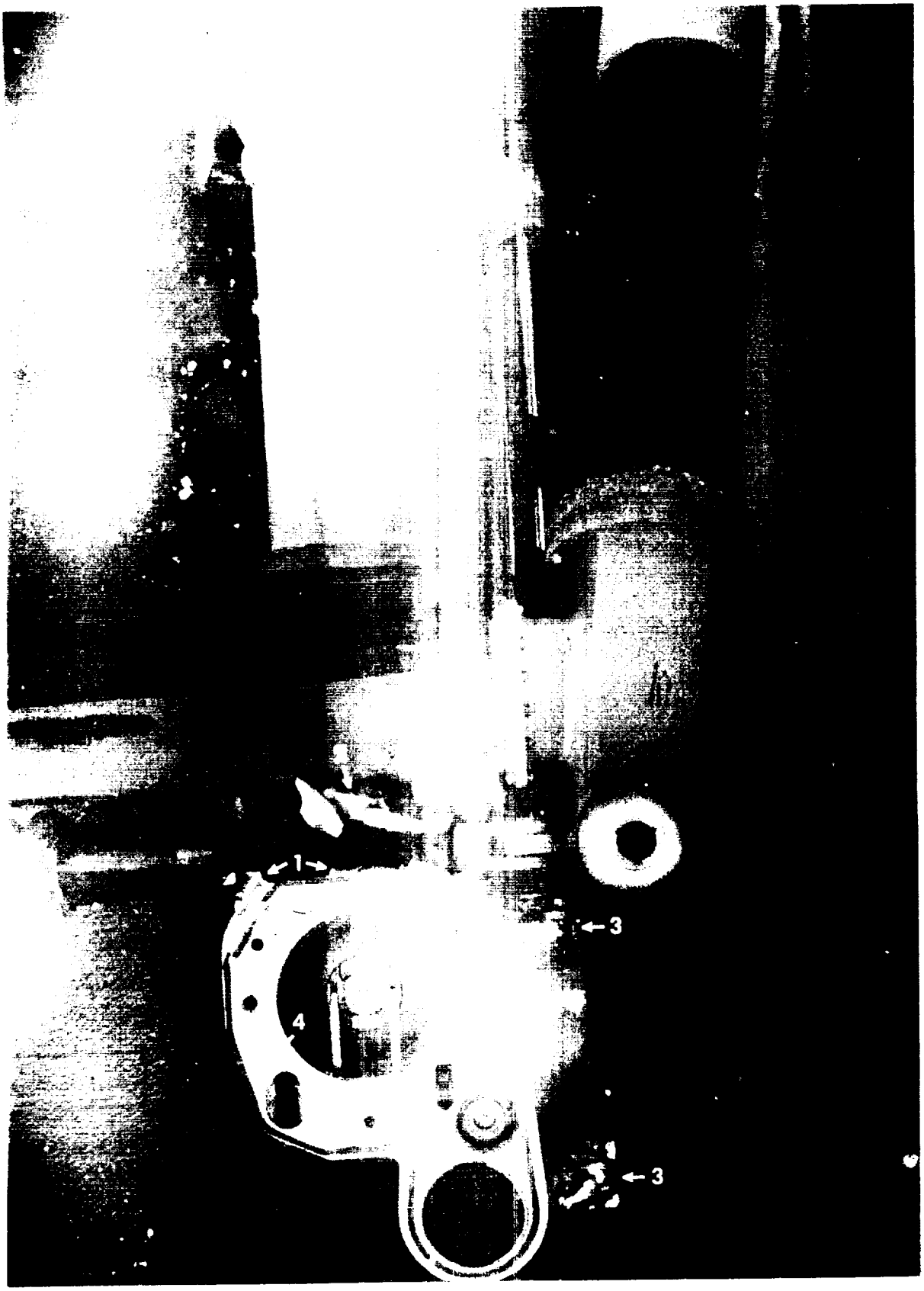


Photo 16: ET/ORB LO2 Umbilical

The LO2 ET/ORB umbilical sustained TPS damage at the top and inboard forward corner (1). Pieces of loose foam from these damaged areas were wedged against the aft side of the crossbeam (2). Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray (3). Lightning contact strips across the forward part of the umbilical and at the 8 o'clock position were missing (4).

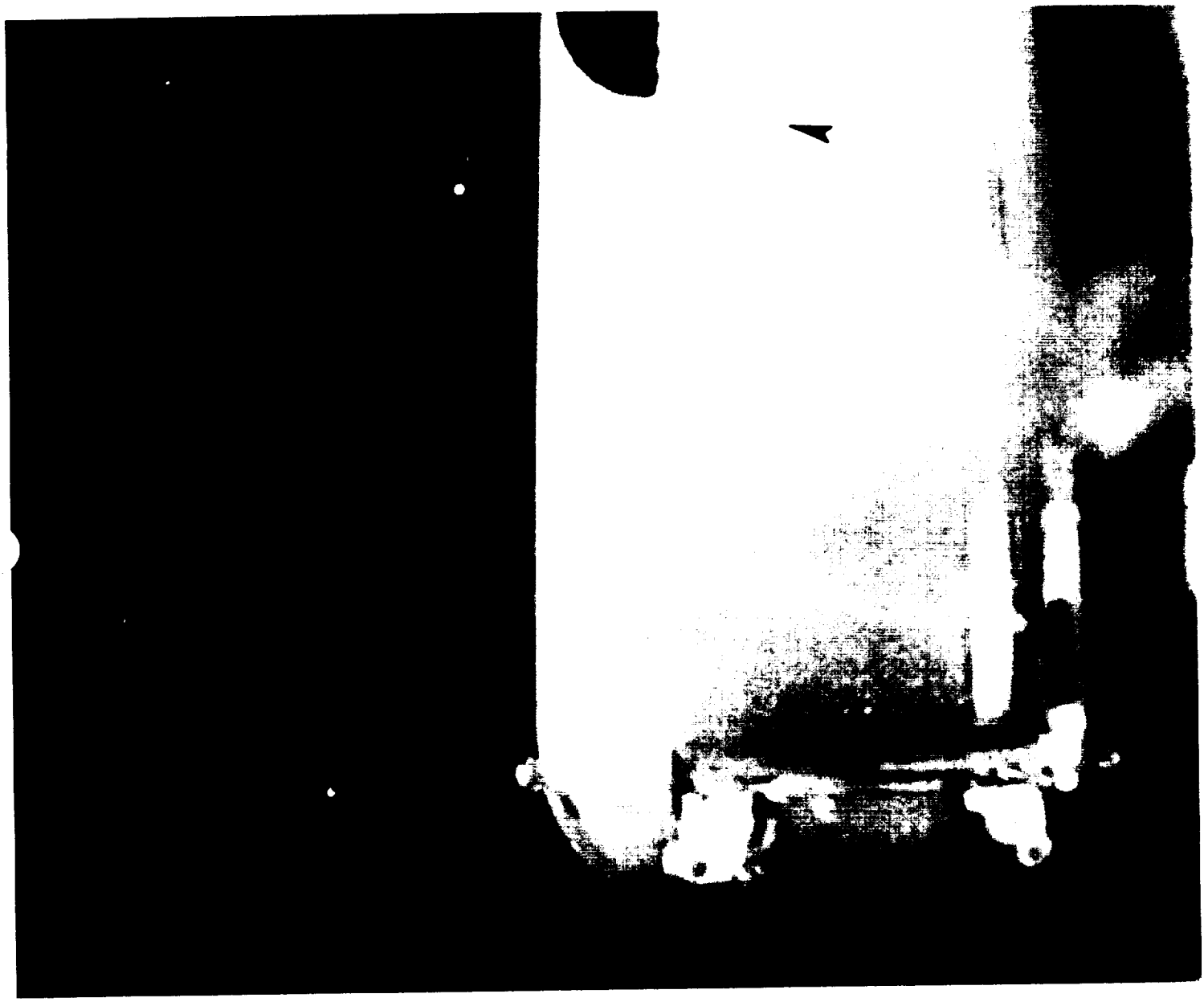


Photo 17: Missing Lightning Contact Strip

A thin, metallic-foil object, believed to be the small lightning contact strip from the LO2 ET/ORB umbilical 8 o'clock position, drifted across the camera field of view after ET separation

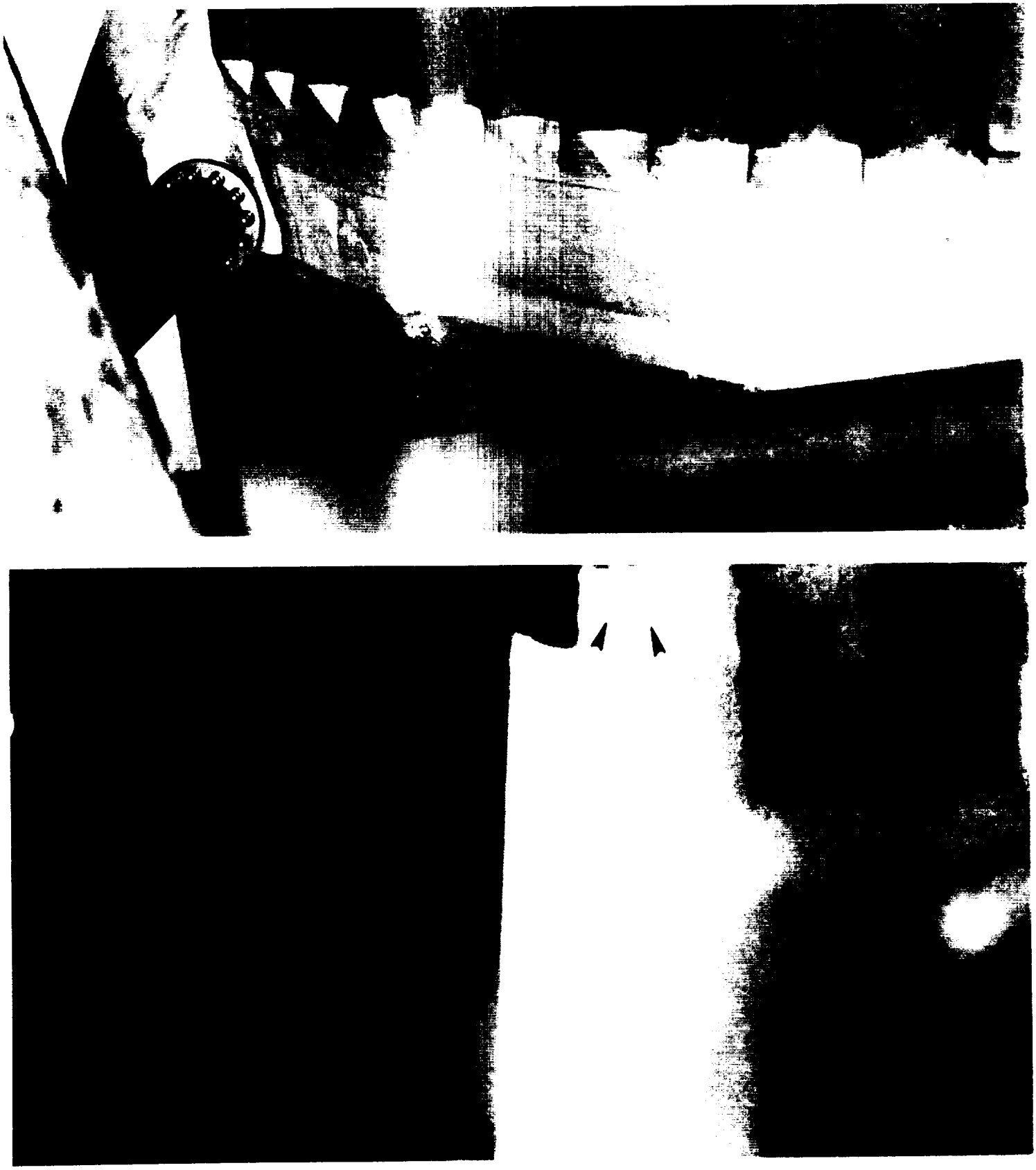


Photo 18: Intact Bipod Jack Pad Closeouts

Pre-Launch view shows the configuration of the new-method bipod jack pad closeouts. Note bright appearance of the BX-250 closeout foam before launch. The closeouts appeared to be unchanged and intact in a view from the ET/ORB umbilical separation cameras.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of thirteen films and videos, which included three 35mm large format films and ten videos, were reviewed. The reduced coverage for landing was caused by need for photo equipment and support personnel on a Titan launch earlier in the day.

Orbiter performance in the Heading Alignment Circle (HAC) and final approach appeared nominal. Wing tip vortices on final approach were visible due to the amount of moisture in the air at the time of landing.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. Left and right main landing gear touchdown was almost simultaneous. The left MLG touched down on the runway centerline. The Orbiter rolled back to centerline after the drag chute was deployed.

Drag chute deployment appeared nominal.

Touchdown of the nose landing gear was smooth.

No significant TPS damage was visible during rollout with the exception of a large site on the lower surface in the right glove area. Rollout and wheel stop were uneventful.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-075 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 23 October 1995. From a debris standpoint, both SRB's were in good condition.

7.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The RH frustum was missing no TPS. The number of debonds (67) over fasteners was greater than average (Figure 1). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position though the upper left cover attach ring had been bent by parachute riser entanglement.

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. Numerous pins and retainer clips were missing from the frustum severance ring. Strands of nylon fiber caught on adjacent clips indicated the damage was caused by the parachute risers after splashdown.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. No K5NA was missing from the separation plane of the upper strut fairing. The ETA ring, IEA, and IEA covers appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. The HDP Debris Containment System (DCS) plungers appeared to have functioned properly though a piece of ordnance debris was wedged against the HDP #3 plunger and prevented full seating. The holddown post #2 stud hole was broached by a stud hang-up at liftoff.

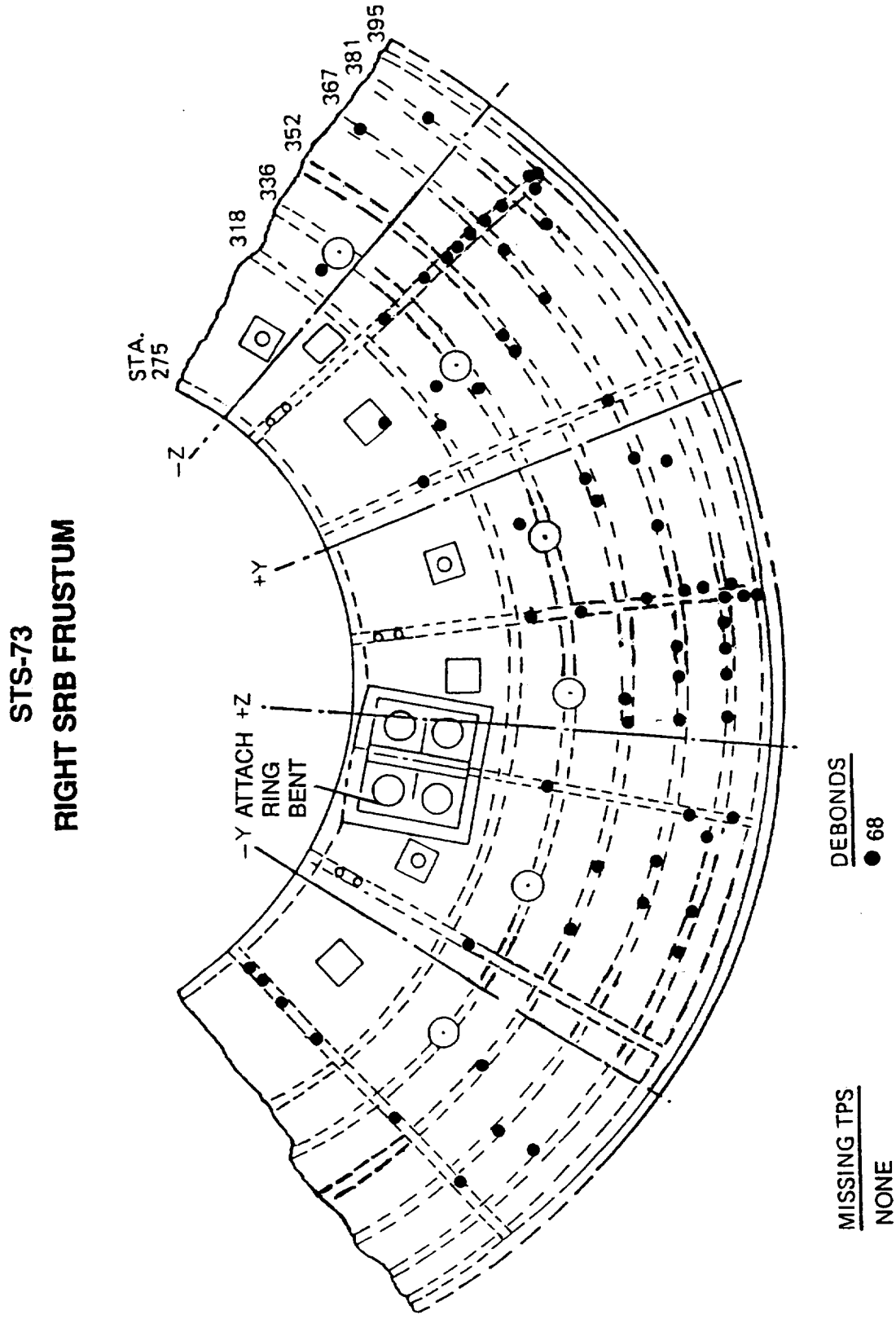


Figure 1 : RH SRB Frustum

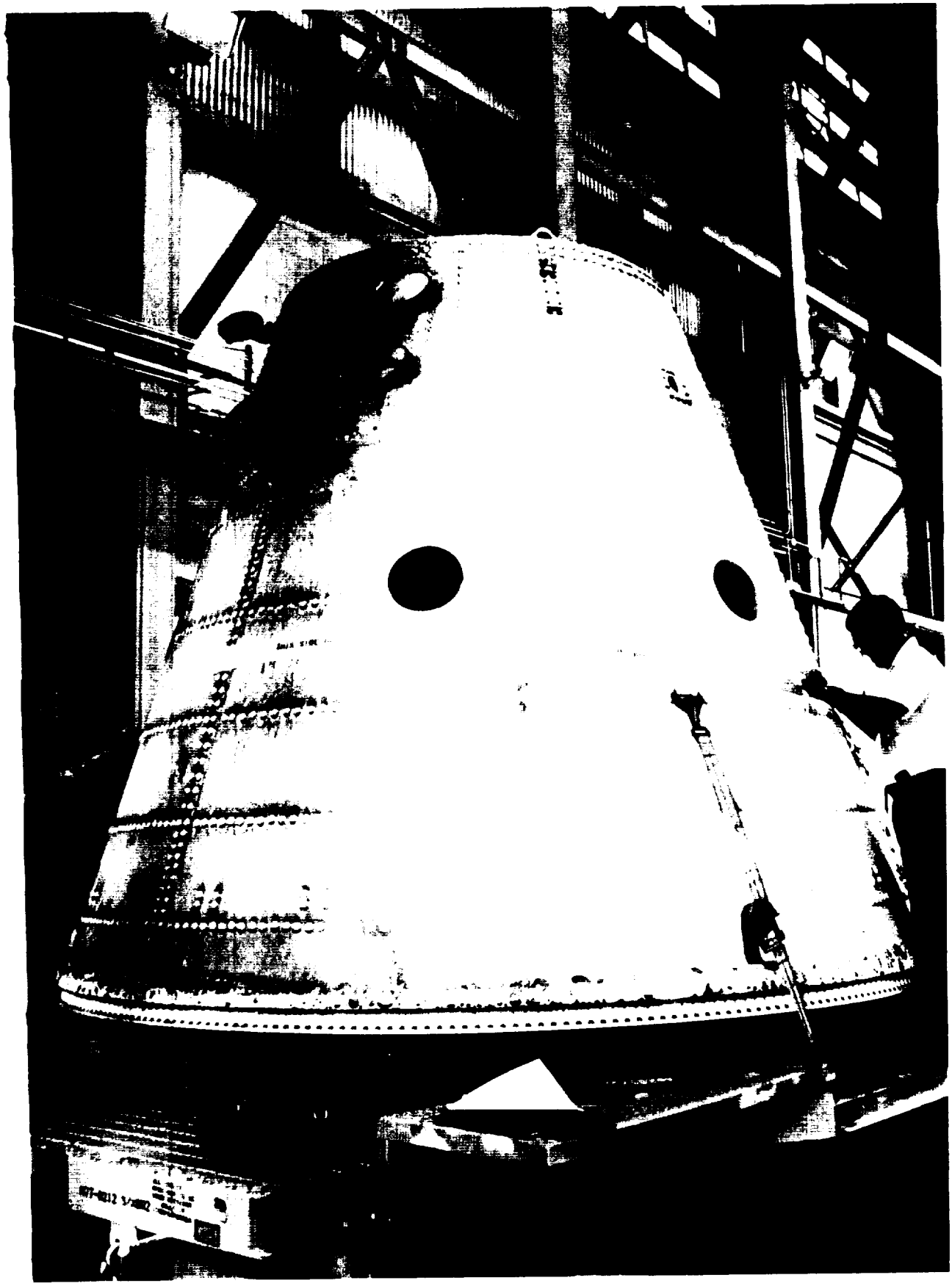


Photo 19: RH Frustum

The RH frustum was missing no TPS. The number of debonds (67) over fasteners was greater than average. The BSM aero heat shield covers had locked in the fully opened position though the upper left cover attach ring had been bent by parachute riser entanglement.

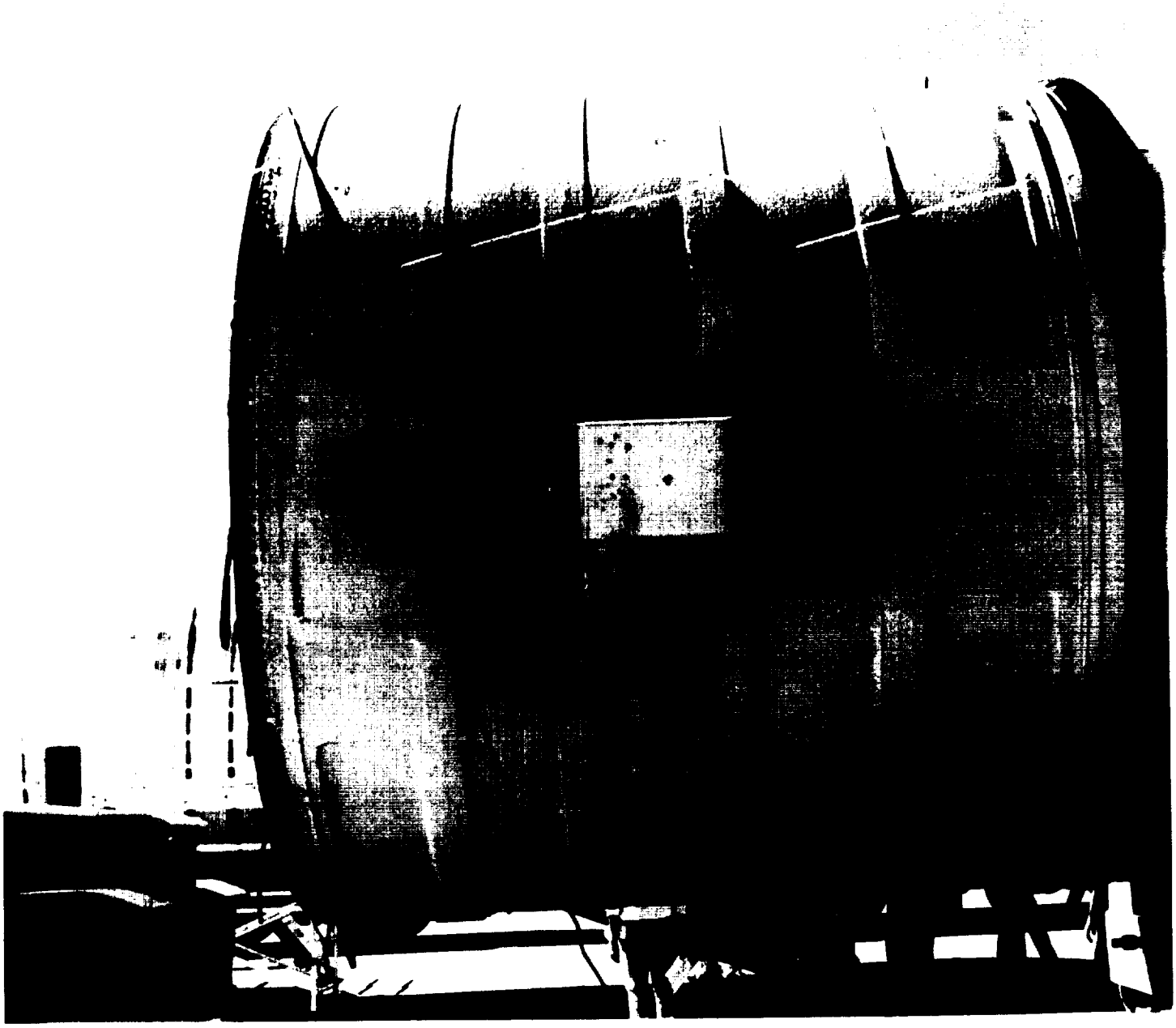


Photo 20: RH Forward Skirt

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied.

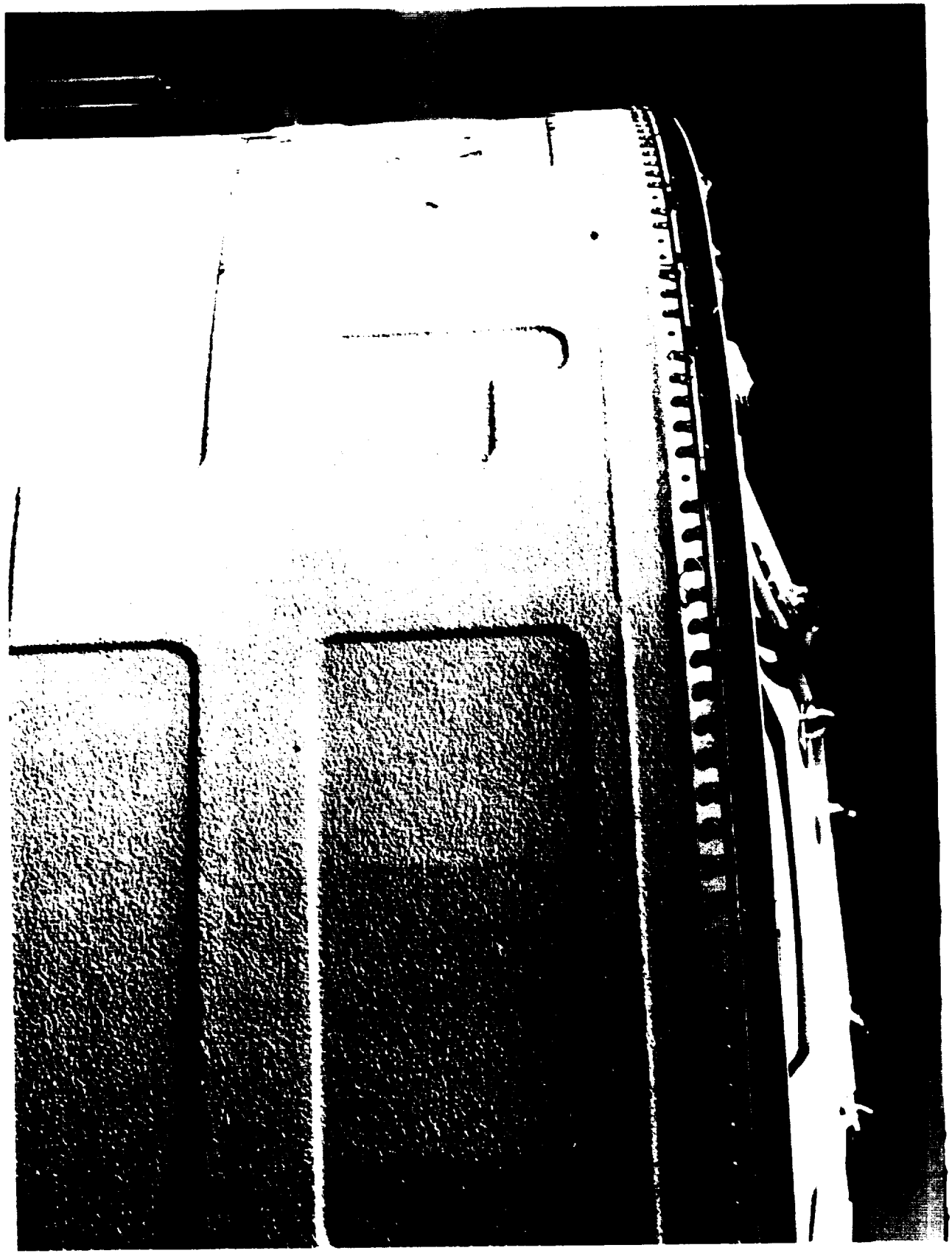


Photo 21: Severance Ring Pins and Retainer Clips

Numerous pins and retainer clips were missing from the frustum severance ring. Strands of nylon fiber caught on adjacent clips indicated the damage was caused by the parachute risers after splashdown.

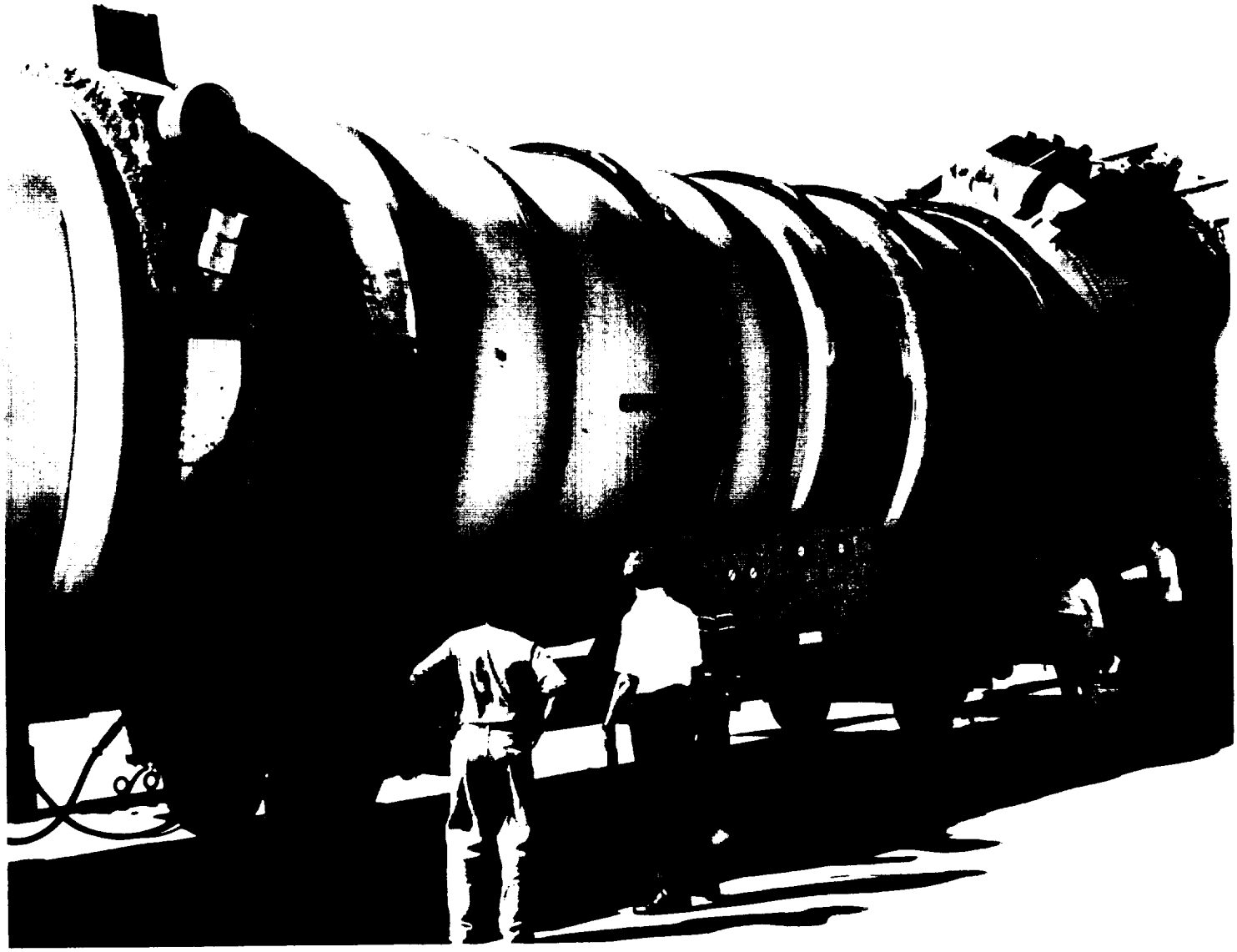


Photo 22: RH Aft Booster/ Aft Skirt

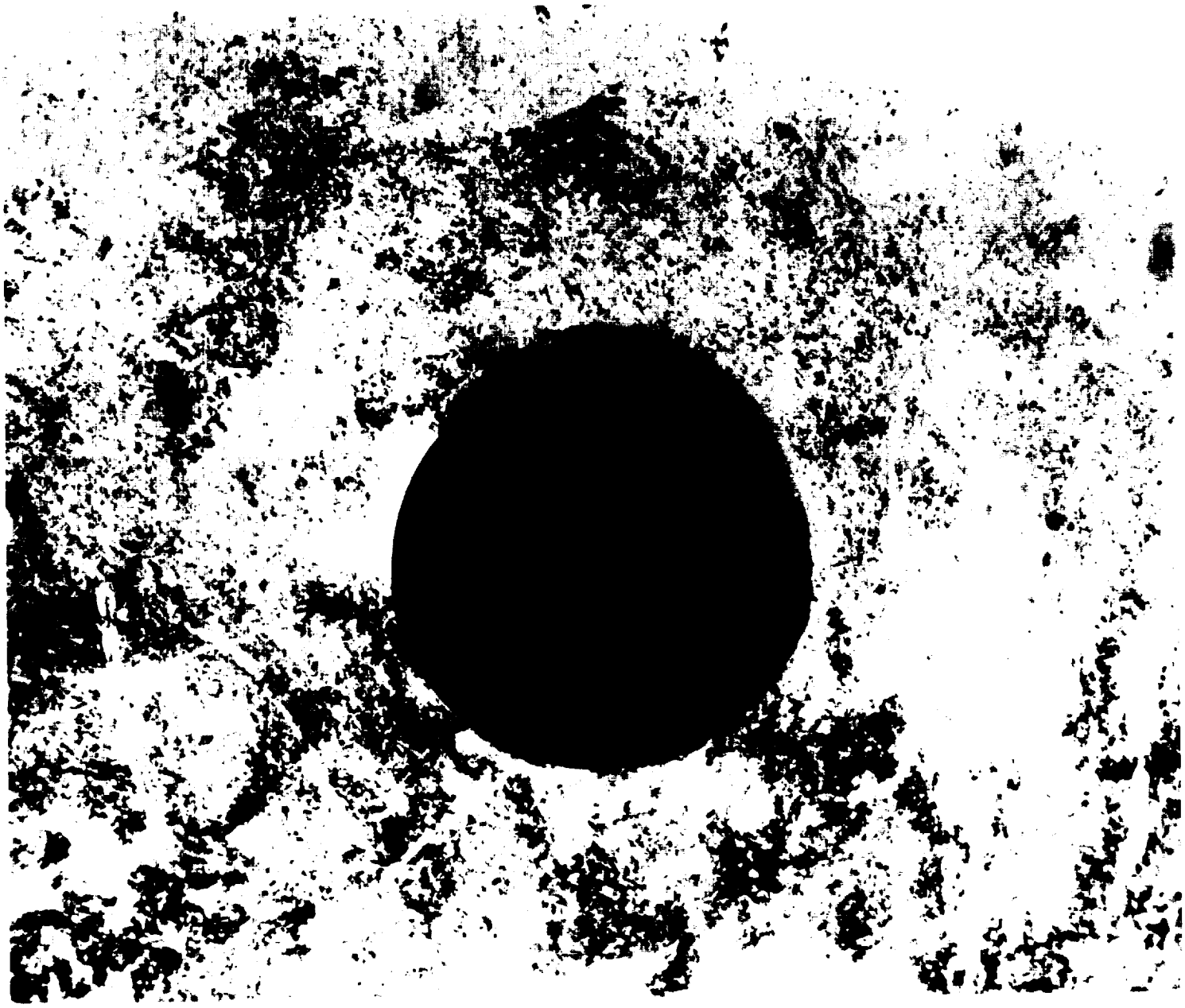


Photo 23: Broached Holddown Post #2 Stud Hole

The holddown post #2 stud hole was broached by a stud hang-up at liftoff

7.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (54) and over acreage (2) was greater than average (Figure 2). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position though the lower left cover attach ring had been bent. The upper left cover was missing. The damage to the BSM covers/attach rings was caused by parachute riser entanglement after splashdown.

The LH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. Some of the pins and retainer clips were missing from the frustum severance ring. Strands of nylon fiber caught on adjacent clips indicated the damage was caused by the parachute risers after splashdown.

The Field Joint Protection System (FJPS) closeouts were in good condition. In general, minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. No K5NA was missing from the separation plane of the upper strut fairing. The ETA ring, IEA, and IEA covers appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.

SRB Post Launch Anomalies are listed in Section 10.

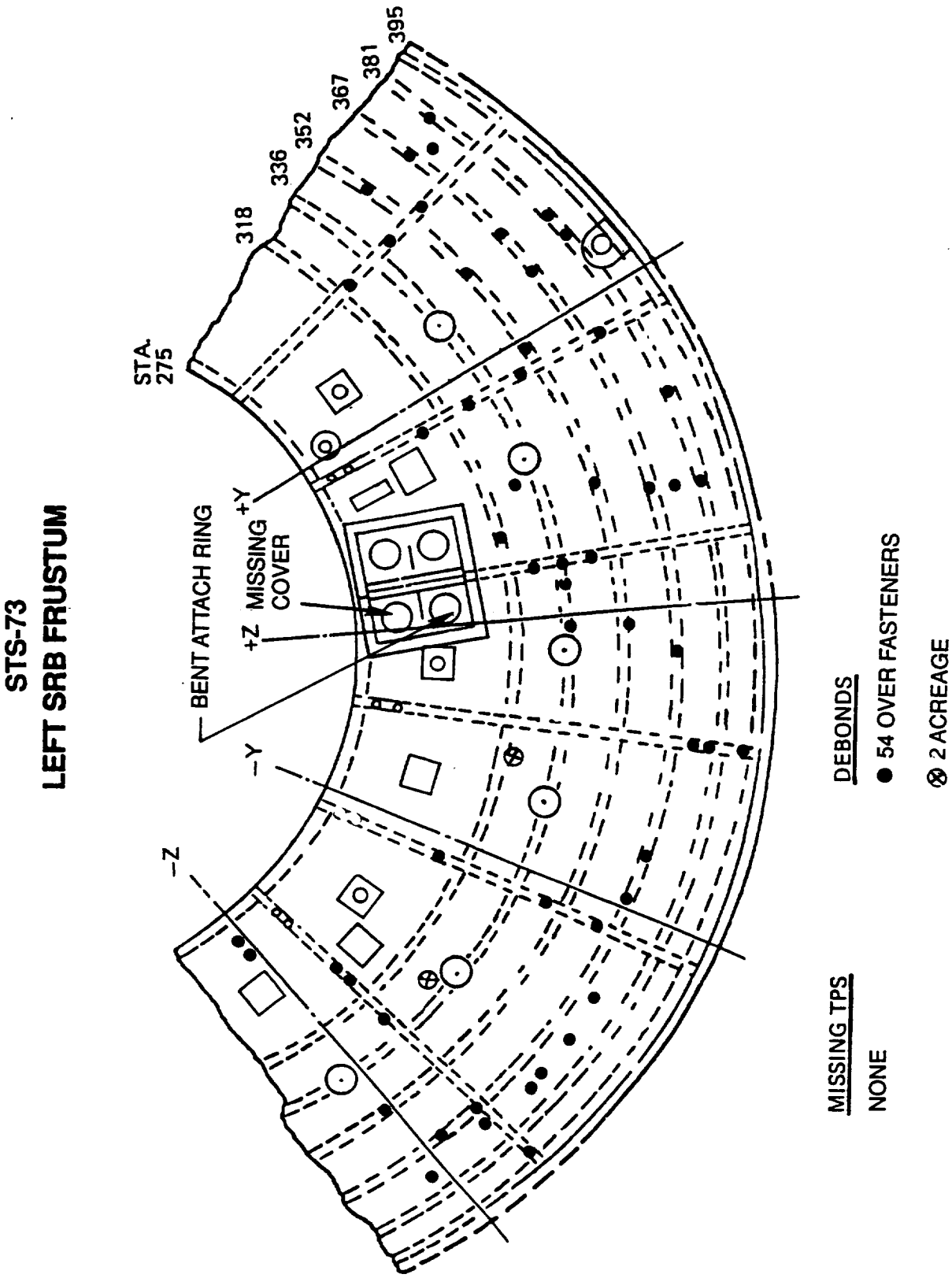


Figure 2 : LH SRB Frustum

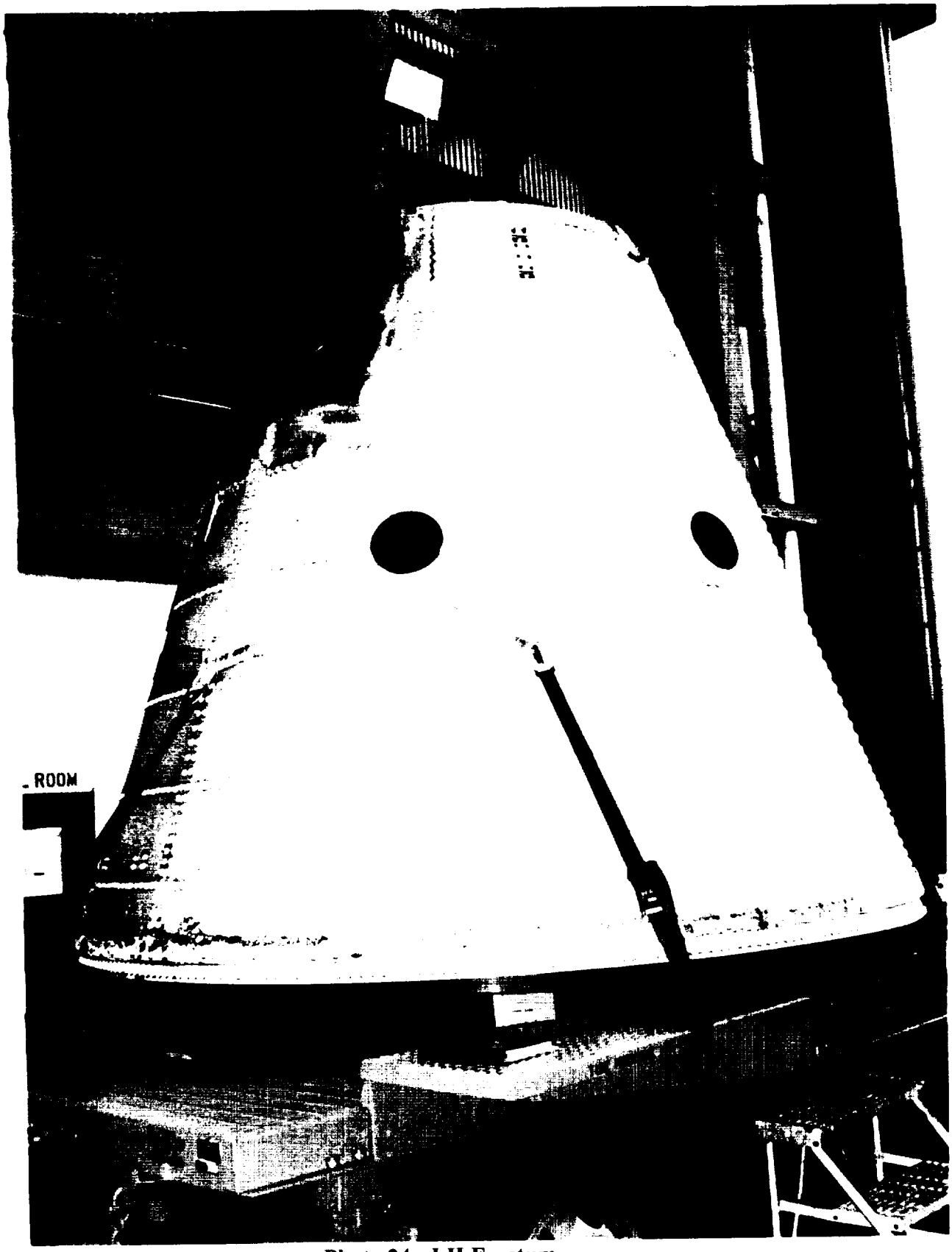


Photo 24: LH Frustum

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (54) and over acreage (2) was greater than average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted.

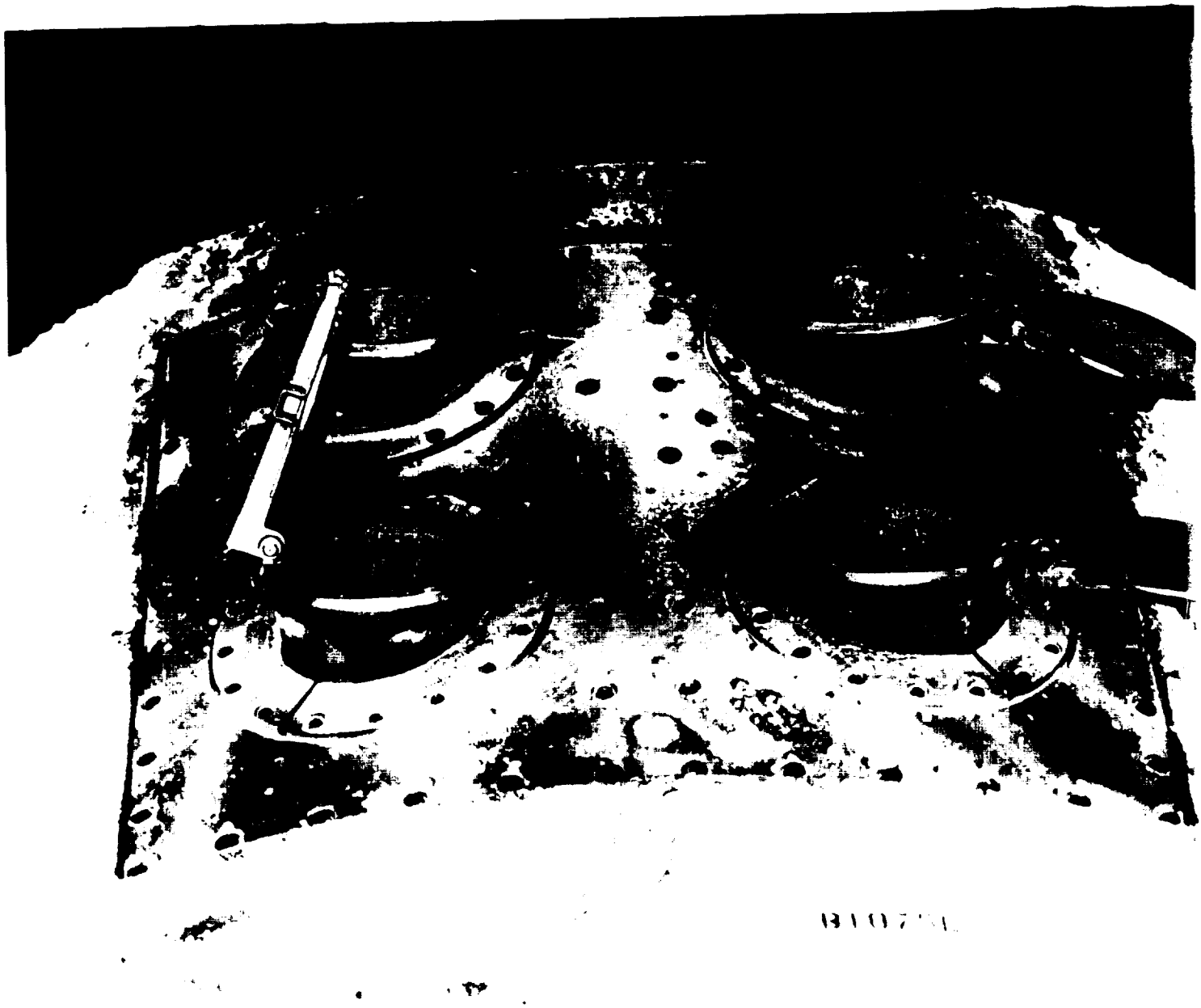


Photo 25: BSM Aero Heat Shield Covers

The BSM aero heat shield covers had locked in the fully opened position though the lower left cover attach ring had been bent. The upper left cover was missing. The damage to the BSM covers/attach rings was caused by parachute riser entanglement after splashdown.

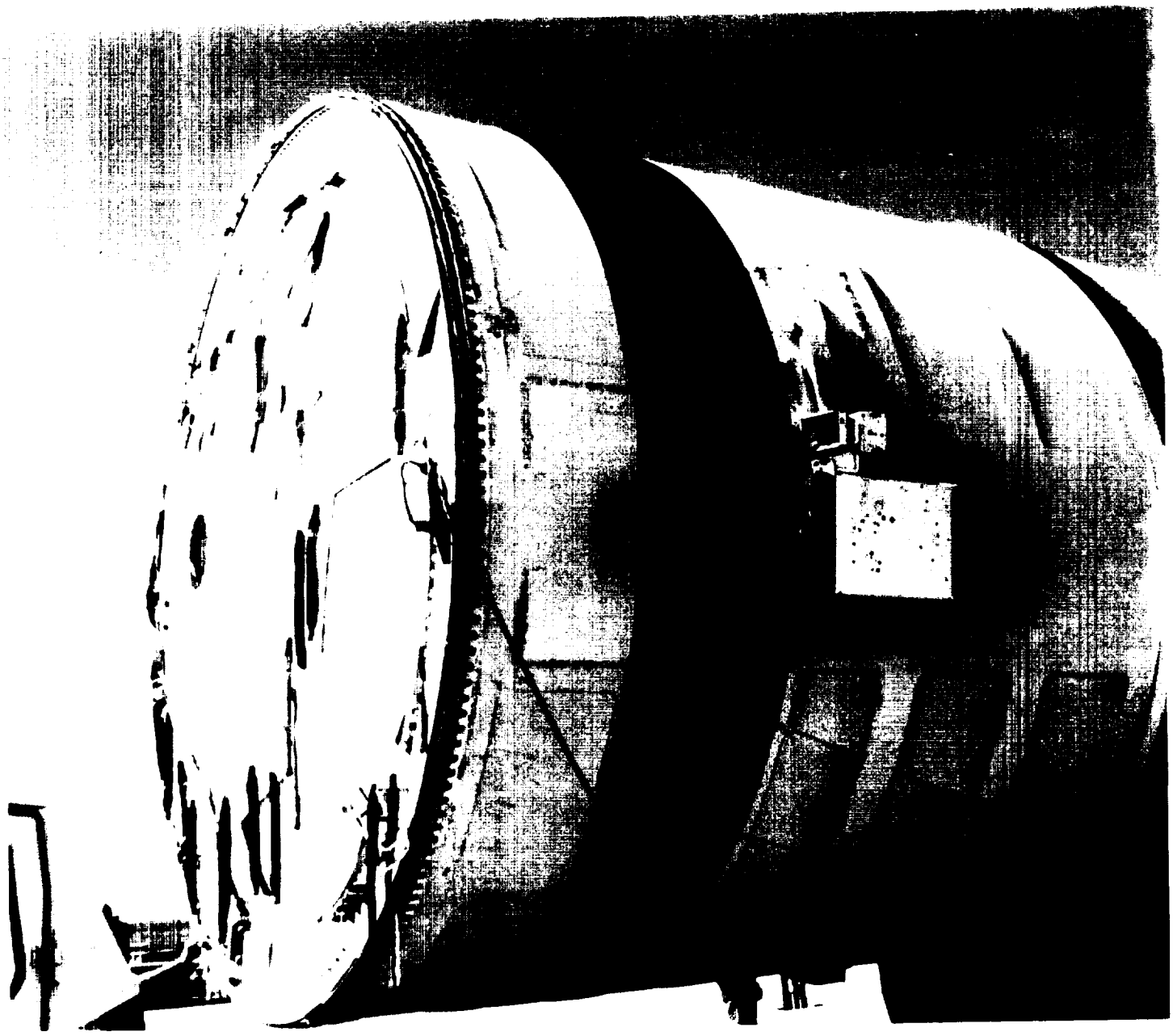


Photo 26: LH Forward Skirt

The LH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied.

Photo 27: Severance Ring Pins and Retainer Clips

Some of the pins and retainer clips were missing from the frustum severance ring. Strands of nylon fiber caught on adjacent clips indicated the damage was caused by the parachute risers after splashdown.

Photo 28: LH Aft Booster/ Aft Skirt

Separation of the aft ET/SRB struts appeared normal. No K5NA was missing from the separation plane of the upper strut fairing. The ETA ring, IEA, and IEA covers appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing. Aft skirt MSA-2 was intact. The HDP Debris Containment System (DCS) plungers were seated and appeared to have functioned properly.

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-102 Columbia was conducted 5-6 November 1995 at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #2. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 147 hits, of which 26 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 56 previous missions of similar configuration (excluding missions STS-23, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was greater than average (Figures 3-6).

The following table breaks down the STS-73 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	17	102
Upper surface	6	35
Right side	0	2
Left side	1	4
Right OMS Pod	1	1
Left OMS Pod	1	3
TOTALS	26	147

The Orbiter lower surface sustained a total of 102 hits, of which 17 had a major dimension of 1-inch or larger. The largest lower surface tile damage site occurred approximately 10 feet forward of the RH MLG wheel well and measured 11.0 inches long by 3.8 inches wide by 0.8 inch maximum depth. The site showed significant signs of re-entry heating including interior glazing, slumping at the tile edge, and melting of the surface coating material.

Aerodynamic flow analyses performed at Rockwell-Downey showed debris sources/origins most likely to have caused this damage would have been located in the ET LO2 tank cable tray area. The LO2 feedline upper bellows, new-method bipod jack pad closeouts, and SRB nose cap ablator were much less likely debris source locations. However, review of ET/ORB umbilical camera films and on-orbit photography of the ET after separation from the Orbiter showed no anomalies that might have been the cause of the damage.

A damage site 2.3 inches long by 0.8 inches wide aft of the RH MLG wheel well exhibited a cavity angled from the tile surface to a depth of approximately 1.5 inches.

Many tile damage sites were located to the right of centerline on the lower surface. Hits in this area along a line from nose to tail are generally attributed to ice impacts from the ET LO2 feedline bellows and support brackets.

Tile damage sites aft of the LH2 and LO2 ET/ORB umbilicals was typical. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

Two gap fillers inboard of the RH MLG wheel well and one gap filler aft of the NLG wheel well protruded from lower surface tiles.

A tile damage site 1.0 inch long by 0.75 inches wide by 0.75 inches deep was located on the left side of the Orbiter nose at the FRCS pod +X-Y-Z corner. The damage site did not exhibit a fore-to-aft impact nor any sharp edges typical of contact damage with adjacent tiles. The possibility of a micrometeorite or on-orbit debris impact while the port side of the vehicle was facing the velocity vector will be investigated.

The tires and brakes were reported to be in good condition for a landing on the KSC concrete runway.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. Numerous damaged clips on the "salad bowl" liner clips were noted: (EO-2: two bent, two missing; EO-3: two bent, six missing). All ET/Orbiter umbilical separation ordnance retention shutters were closed properly. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. Although no debris was found on the runway after wheel stop beneath the umbilical cavities, a 2-inch long by 1/4-inch wide by 1/8-inch thick piece of white RTV had fallen from the LH2 ET/ORB umbilical plate onto one of the left ET door hinges. A scorched piece of vinyl or mylar tape 1-inch square adhered to the umbilical 16mm camera window.

All three Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition with no missing material. The DMHS blankets at the SSME #1 5:00 and 7:00 o'clock positions were torn and frayed. No body flap hinge stub (piano key) tiles were missing or damaged. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged. Two tiles on the left side of the rudder/speed brake were missing corner material 1.0 inch by 1.0 inch by 0.5 inches down to the SIP. These two tile damage sites were caused by vibration, not debris impacts.

No ice adhered to the payload bay door. A white residue was observed around the waste water dump nozzles. No unusual amounts of tile damage occurred on the leading edges of the OMS pods. However, one small tile damage site on the leading edge of the vertical stabilizer SILTS pod measured 0.75 inches long by 0.25 inches wide by 0.5 inches deep.

Orbiter windows #3 and #4 exhibited moderate hazing and streaking. A light haze was present on the other windows. Damage to the window perimeter tiles was concentrated on windows #2, #3, and #5. Several tile damage sites were caused by impacts from FRCS paper cover pieces and RTV. Some of the damage sites were previous tile repairs that had vibrated loose. Five damage sites in the tiled area between windows #3 and #4 were also noted.

The post landing walkdown of Runway 33 was performed immediately after landing. No flight hardware was found on the runway. All drag chute hardware was recovered and appeared to have functioned normally. No unexpected hardware damage was observed on any of the drag chute components.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was greater than average when compared to previous missions (Figure 7).

Orbiter Post Launch Debris Anomalies are listed in Section 10.

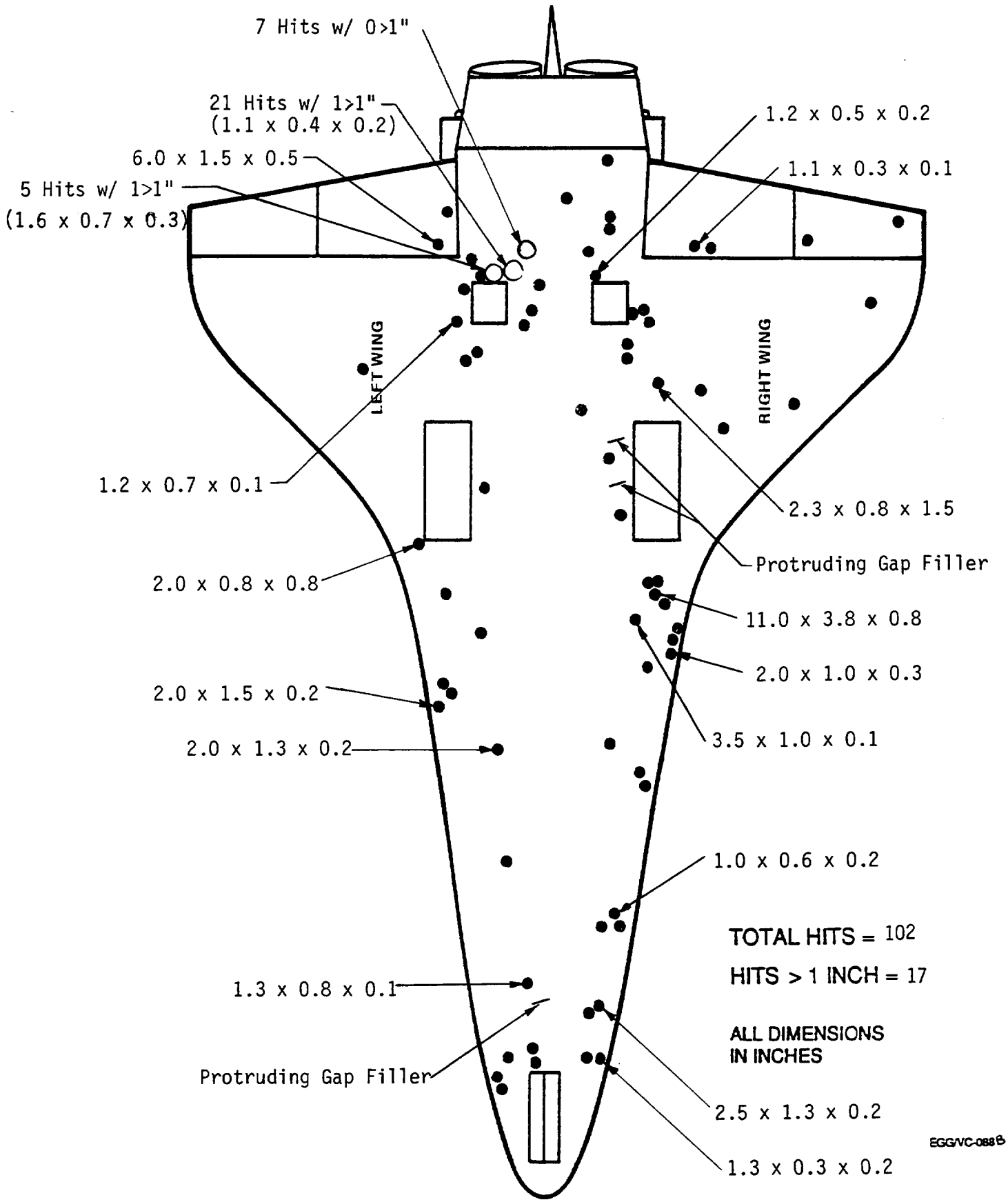
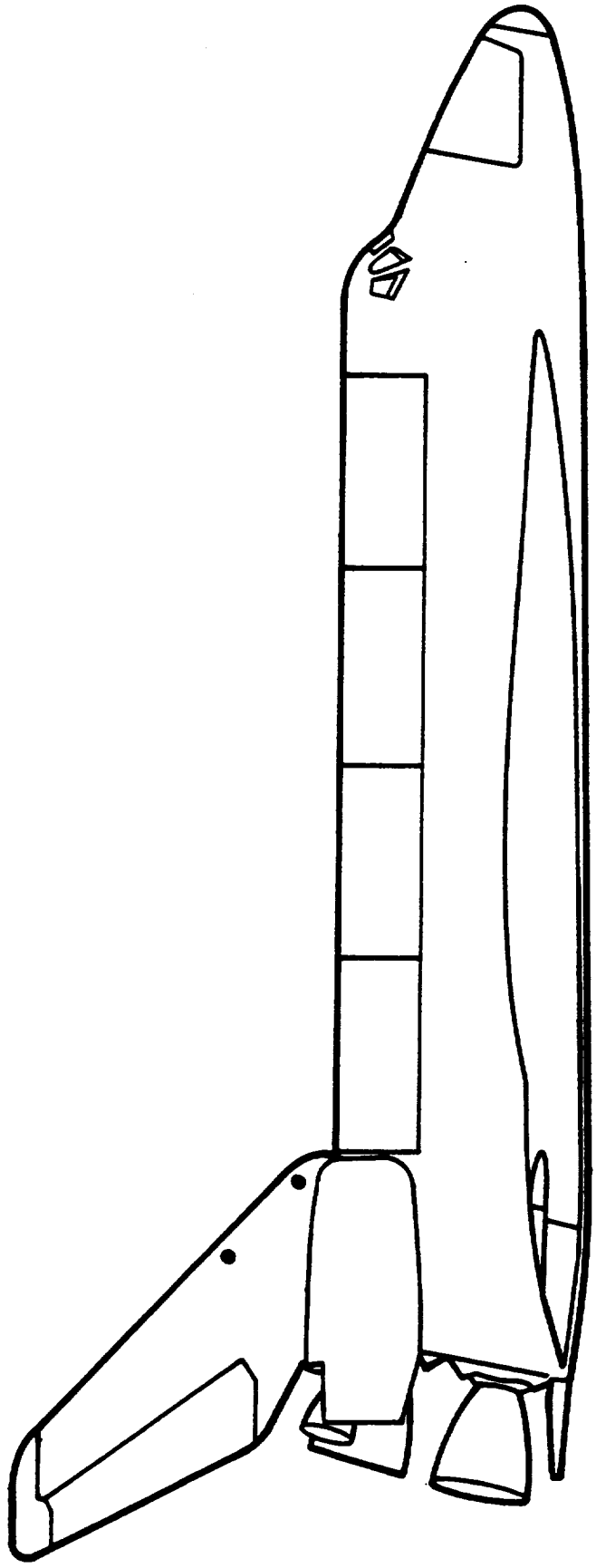


Figure 3 : Orbiter Lower Surface Debris Map



TOTAL HITS = 2

HITS > 1 INCH = 0

Figure 4 : Orbiter Right Side Debris Map

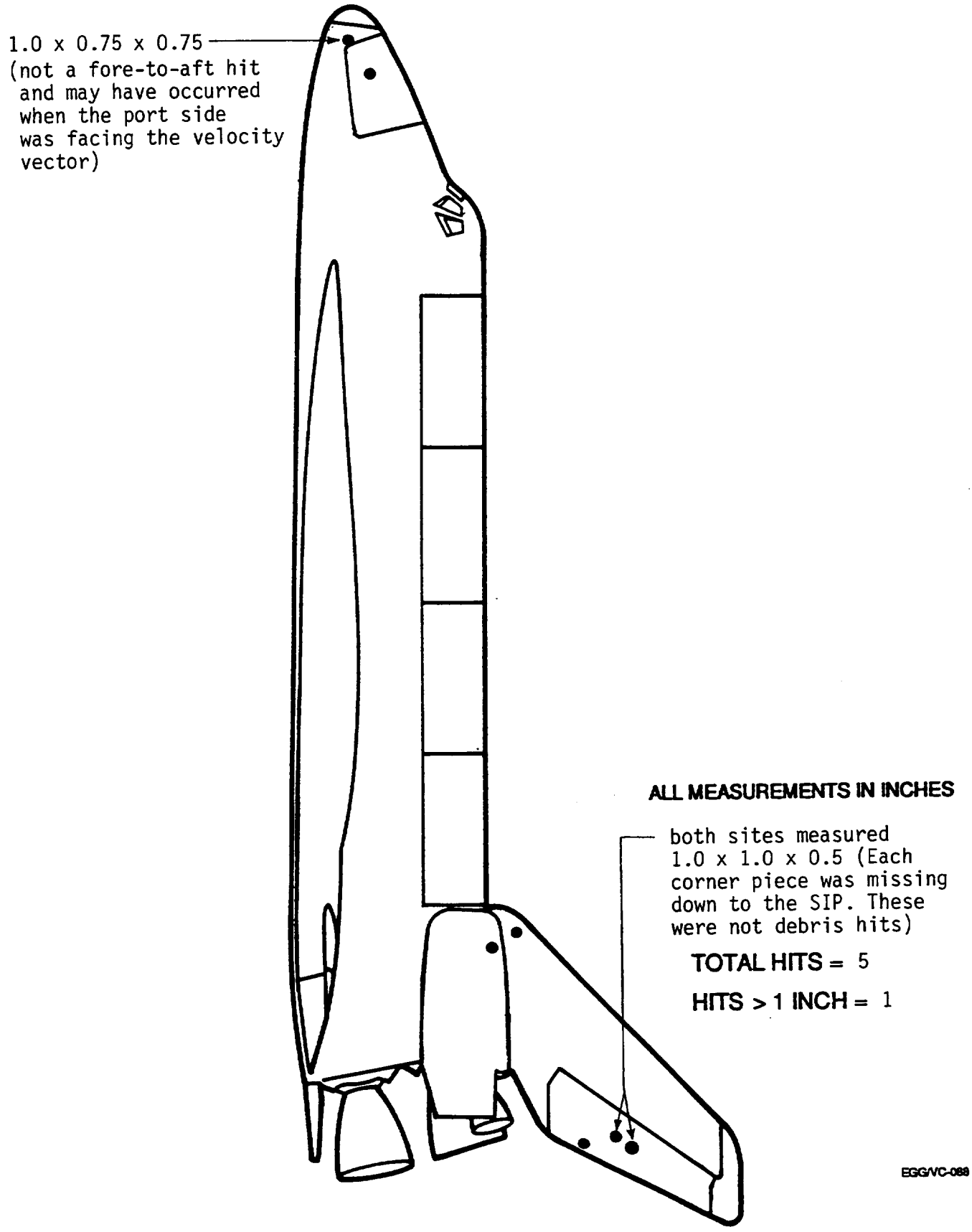


Figure 5 : Orbiter Left Side Debris Map

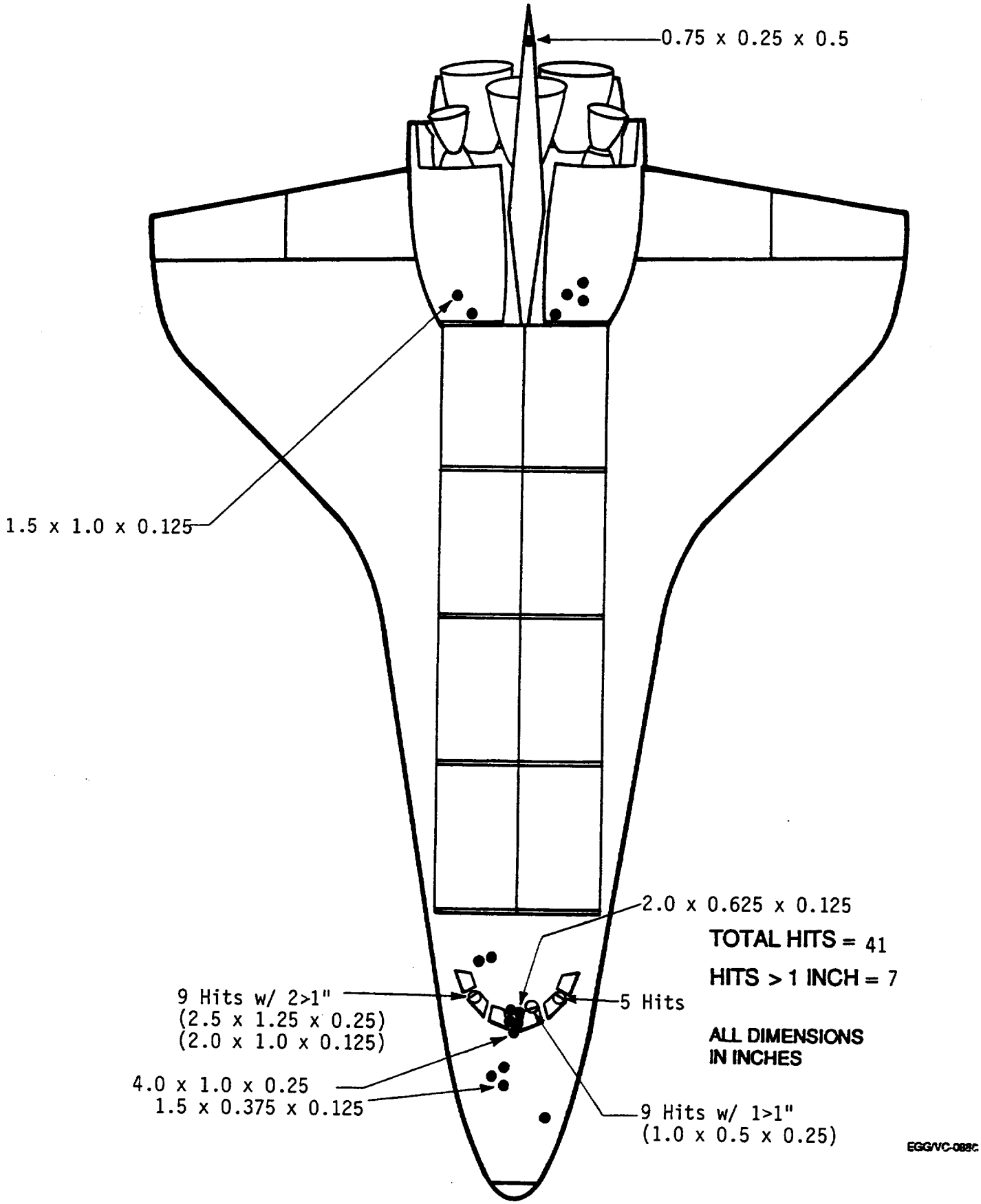


Figure 6 : Orbiter Upper Surface Debris Map

	LOWER SURFACE		ENTIRE VEHICLE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	15	80	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
AVERAGE	14.1	92.0	21.0	132.1
SIGMA	7.2	43.9	9.8	54.4
STS-73	17	102	26	147

MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCE

Figure 7 : Orbiter Post Flight Debris Damage Summary

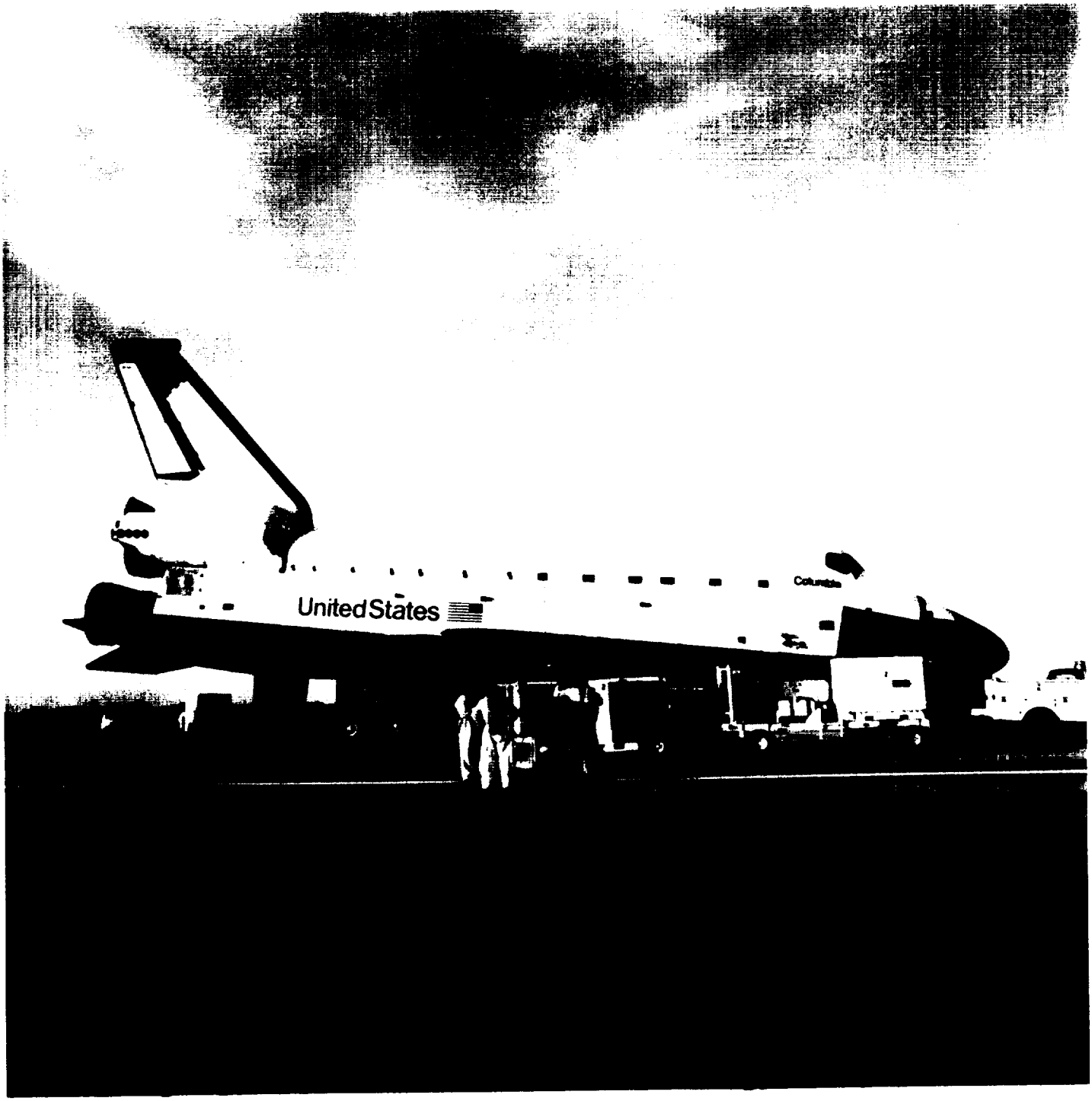


Photo 29: Overall View of Orbiter Right Side

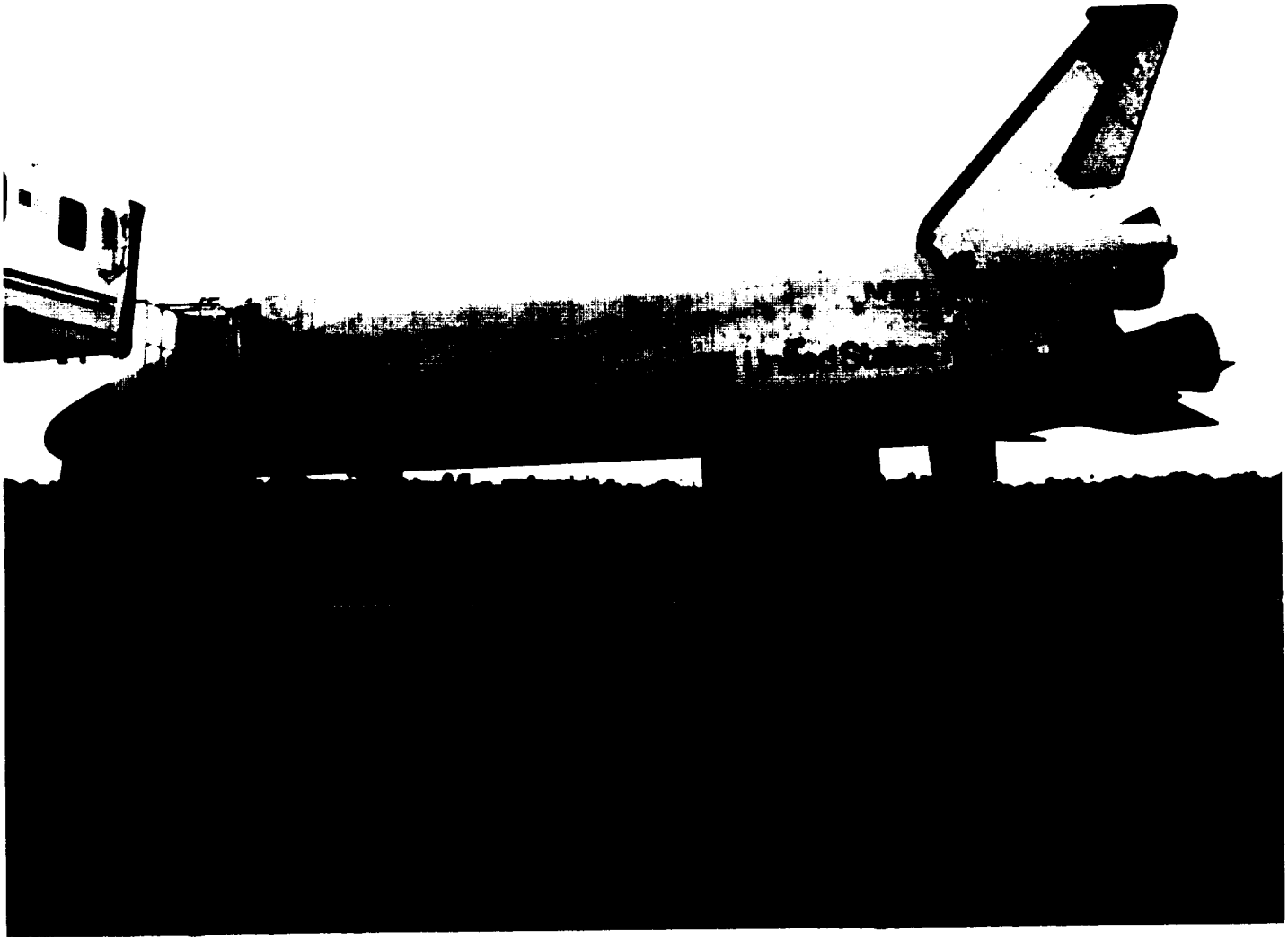


Photo 30: Overall View of Orbiter Left Side

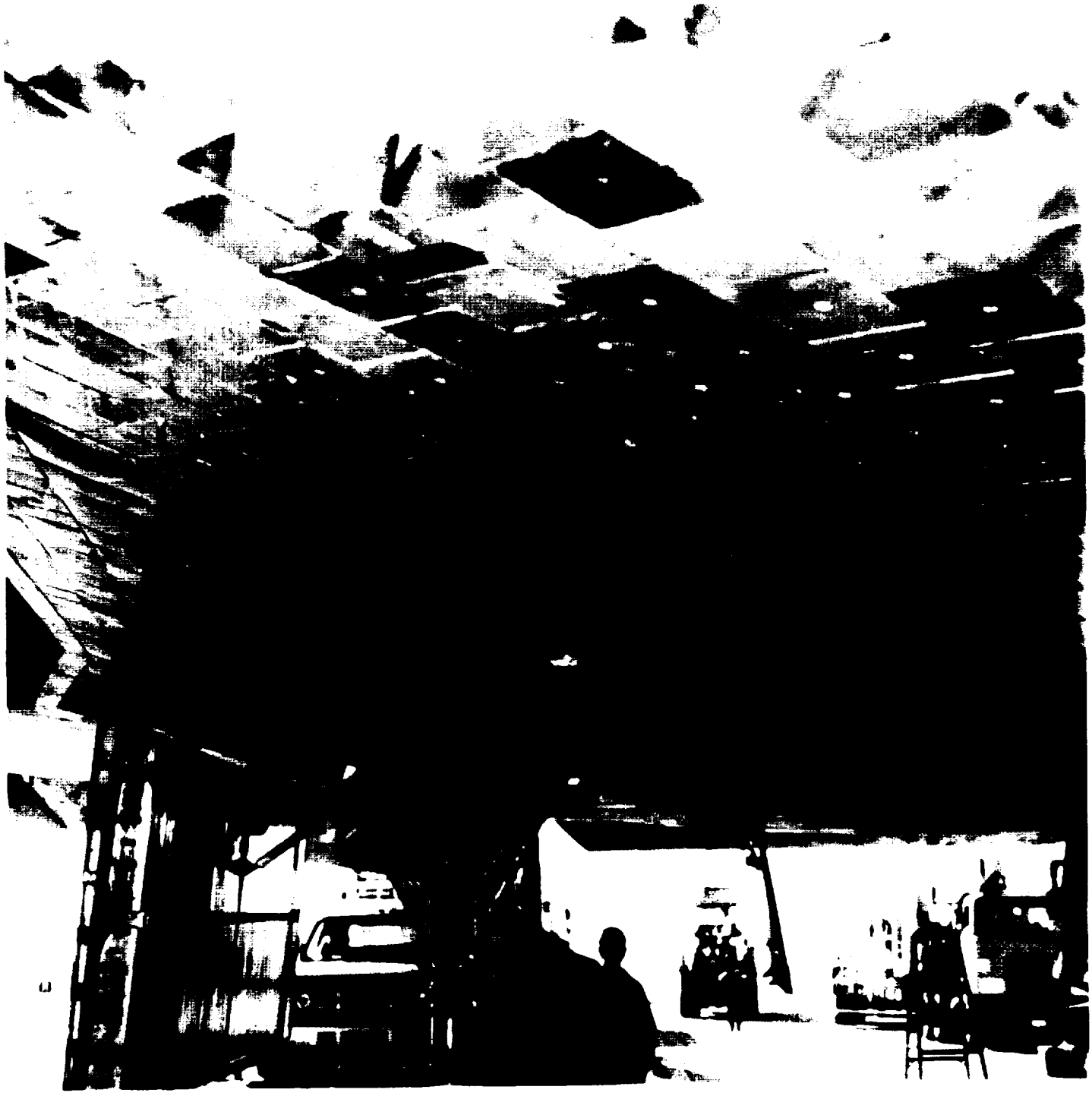


Photo 31: Lower Surface Tile Damage

The Orbiter lower surface sustained a total of 102 hits, of which 17 had a major dimension of 1-inch or larger. The largest lower surface tile damage site occurred approximately 10 feet forward of the RH MLG wheel well.

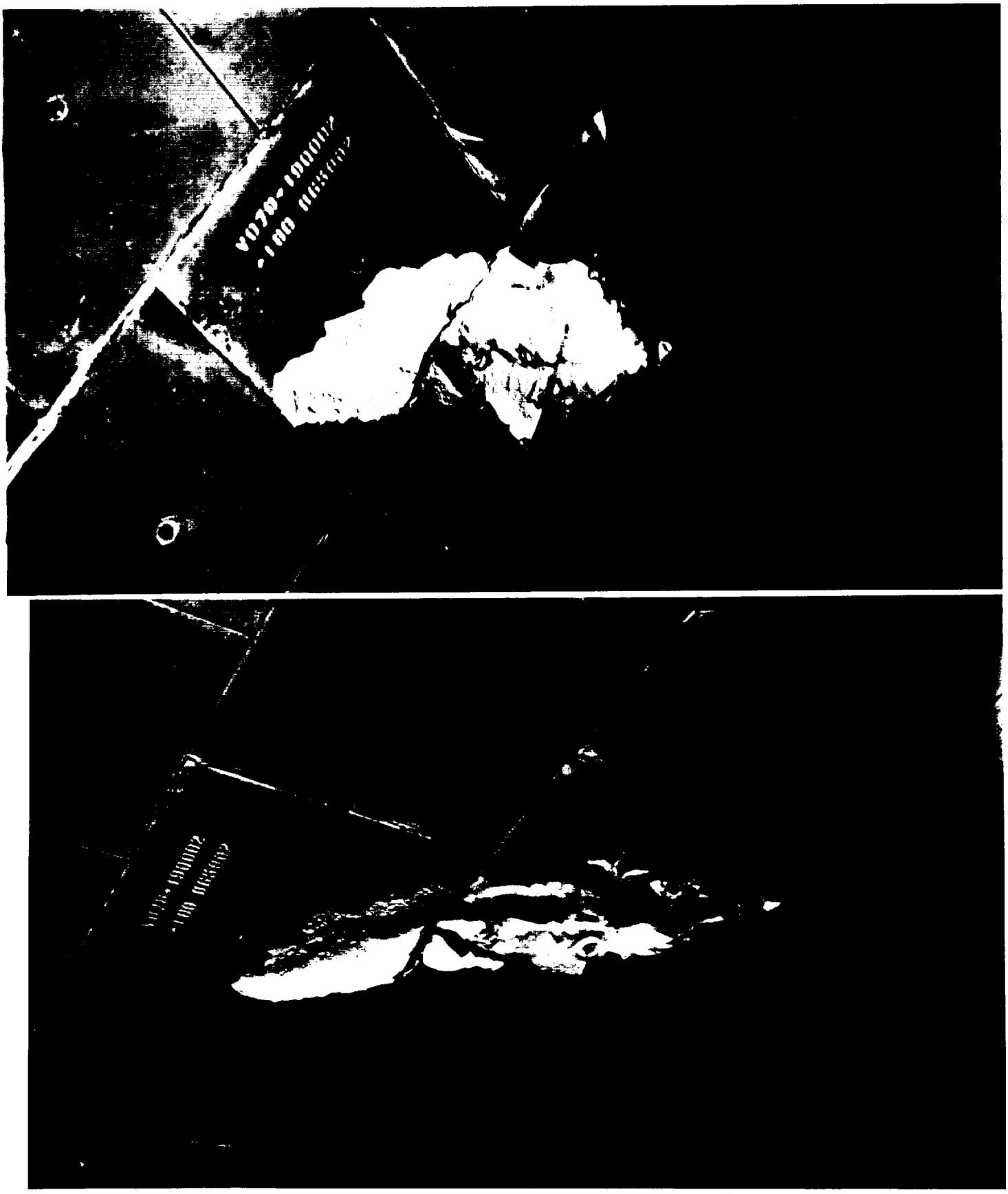


Photo 32: Lower Surface Tile Damage

Two views showing a large tile damage site on the lower surface. The damage site, which measured 11.0 inches long by 3.8 inches wide by 0.8 inch maximum depth, showed significant signs of re-entry heating including interior glazing, slumping at the tile edge, and melting of the surface coating material.

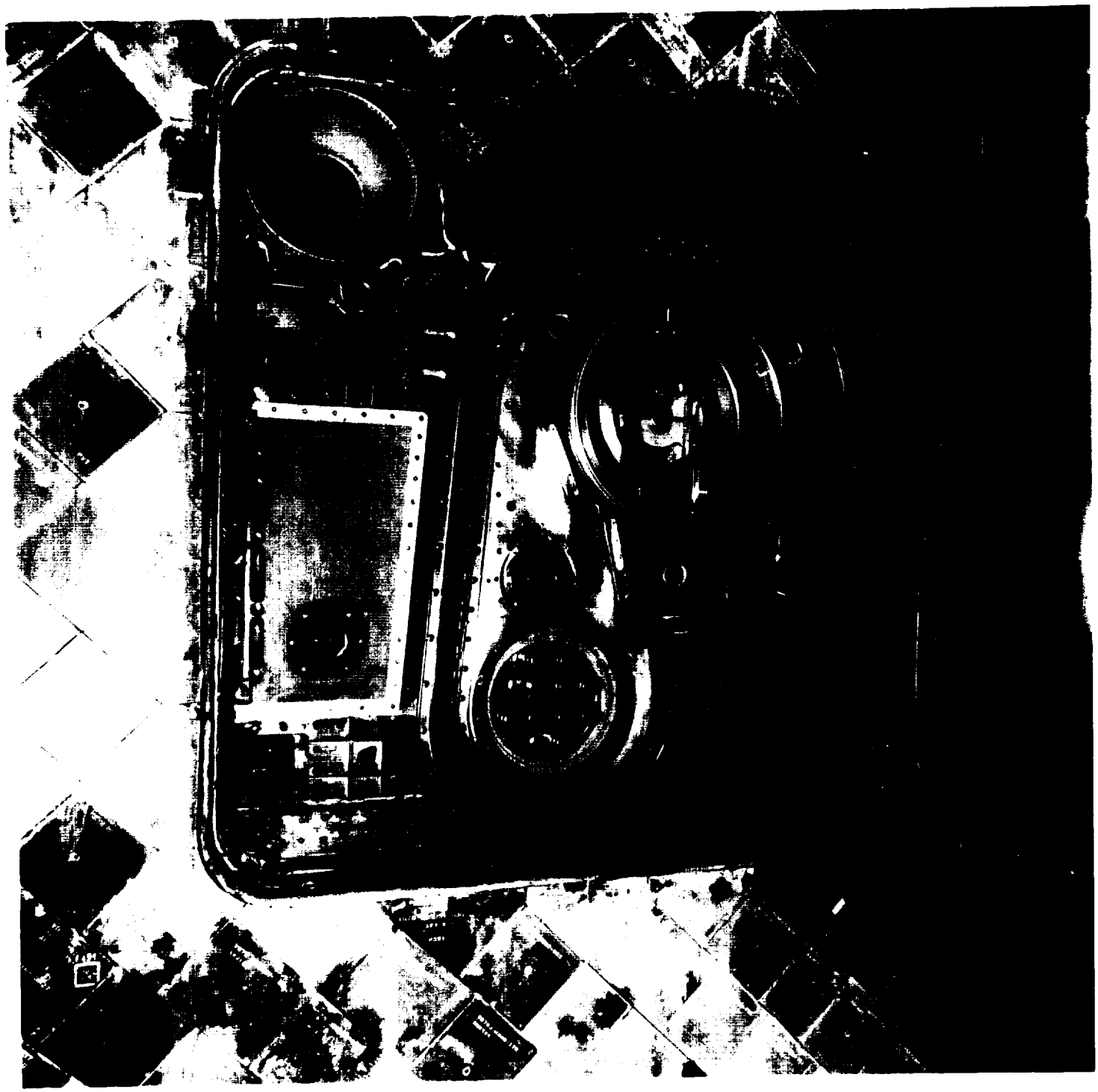


Photo 33: LO2 ET/ORB Umbilical

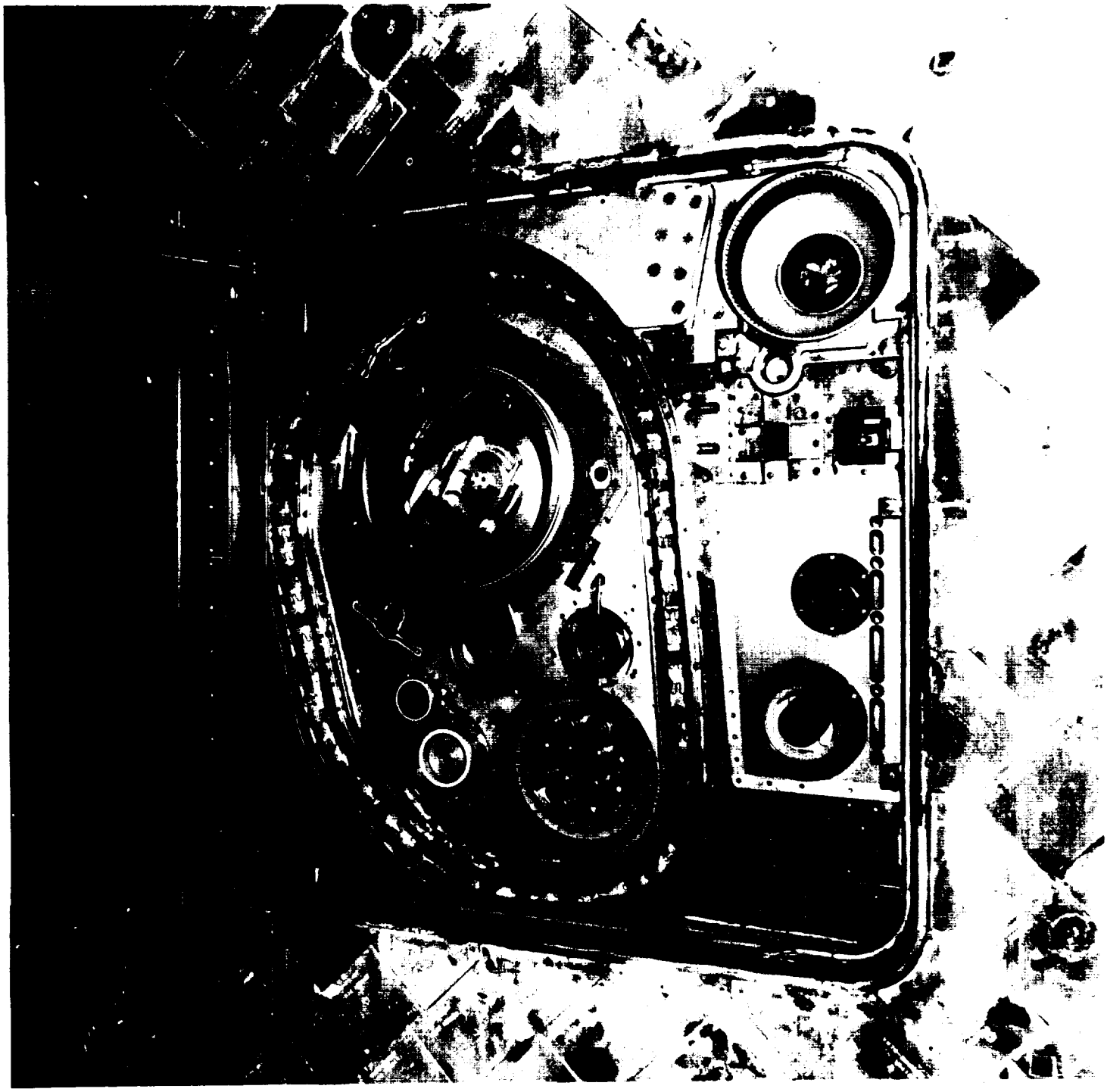


Photo 34: LH2 ET/ORB Umbilical

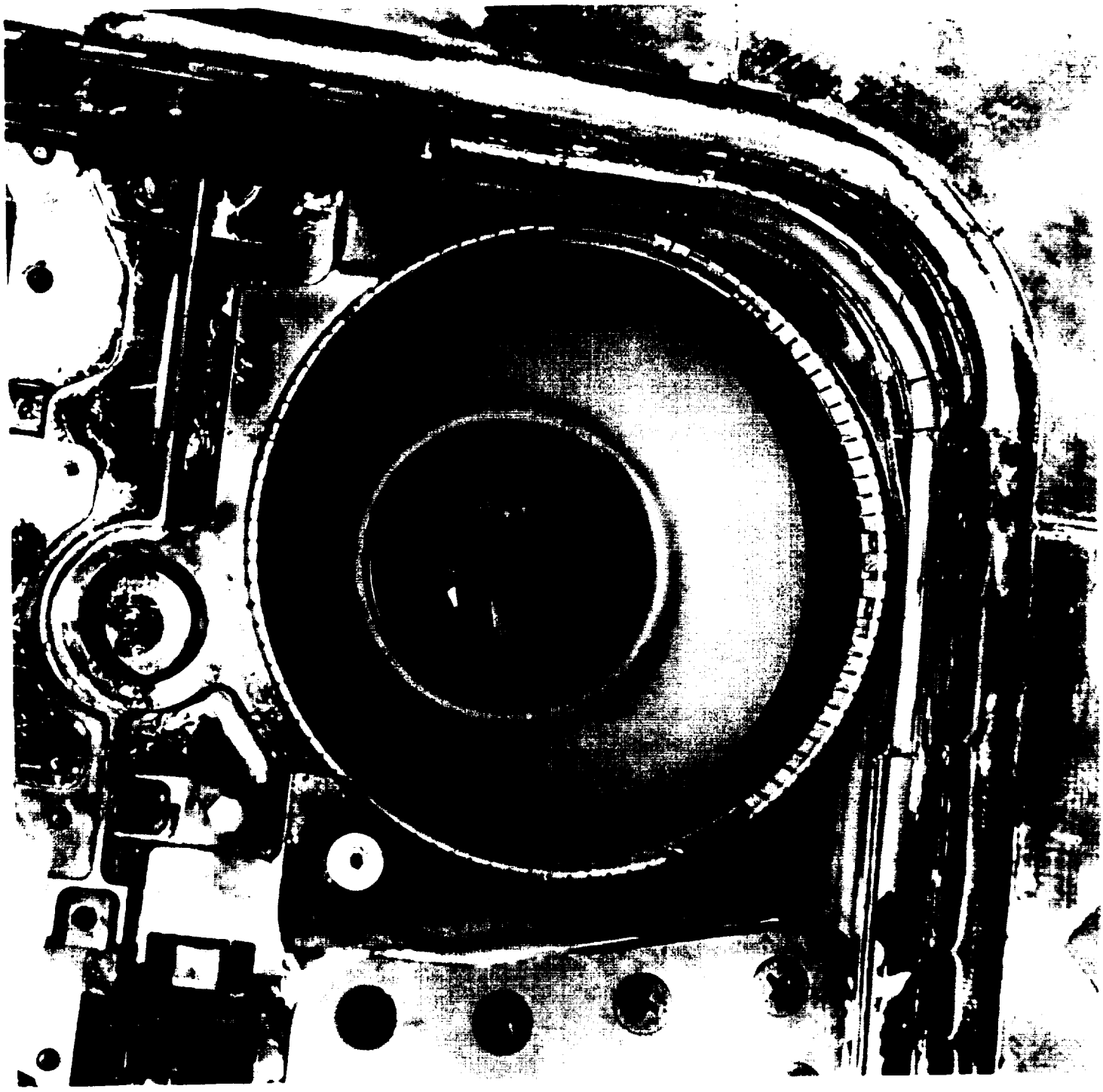


Photo 35: ET/ORB Fitting Lining Clips

ET/Orbiter separation devices EO-2 and EO-3 functioned normally. Numerous damaged clips on the "salad bowl" liners were noted: EO-2: two bent, two missing; EO-3: two bent, six missing.

Photo 36: Windows and Perimeter Tile Damage

Orbiter windows #3 and #4 exhibited moderate hazing and streaking. A light haze was present on the other windows. Damage to the window perimeter tiles was concentrated on windows #2, #3, and #5. Several tile damage sites were caused by impacts from FRCS paper cover pieces and RTV. Some of the damage sites were previous tile repairs that had vibrated loose.

9.0 DEBRIS SAMPLE LAB REPORTS

A total of eight samples were obtained from OV-102 Columbia during the STS-73 post landing debris assessment at Kennedy Space Center. The submitted samples consisted of 8 wipes from Orbiter windows #1-8. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves both the placing and the correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries.

9.1 ORBITER WINDOWS

Samples from the Orbiter windows indicated exposure to facility environment, SRB BSM exhaust (metallic particulate), landing site materials (earth minerals), Orbiter Thermal Protection System (tile, tile repair, and glass insulation), Orbiter RCS nozzle cover adhesive, paints and primer from various sources. There was no apparent vehicle damage related to these residuals.

9.2 ORGANIC ANALYSIS

The results of the STS-73 organic analysis revealed the presence of plastic polymers (Orbiter window covers), RTV (Orbiter RCS nozzle cover adhesive), sealant, calcium carbonate-filled epoxy sealer, and paint. These types of organic particulate are consistent throughout the samples and with those of the last several STS flights.

9.3 STS-69 ORGANIC ANALYSIS

The results of the recently-received STS-69 organic sample analysis indicated the presence of plastic polymers (Orbiter window covers) and RTV (Orbiter RCS nozzle cover adhesive) and paint. These particulate types are consistent throughout the samples and appear to be characteristic of that seen in the last several flights.

9.4 NEW FINDINGS

This set of post-flight debris residual samples led to no new findings. The variety of residual material continues to be representative of that documented in previous mission sampling (reference Figure 8).

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Umbilical	Other
73	Metallics - Fac. Env./BSM Residue (SRB) Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Earth Minerals Organics - Plastic polymers, sealant, RTV(RCS thruster nozzle cover adhesive) Paint and primer				
69	Metallics - Fac. Env./BSM Residue (SRB) RTV, Tile filler (ORB TPS) Insulation glass (ORB TPS) Earth minerals Building type insulation Organics -RTV(RCS adhesive),Plastic polym Orbiter window polish residue Paint and primer				
70	Metallics - Fac. Env./BSM Residue (SRB) RTV, Tile filler (ORB TPS) Insulation glass (ORB TPS) Earth minerals Building type insulation Organics - RTV, Plastic polymers RTV - RCS thruster nozzle cover adhesive Paint and primer				
71	Metallics - Fac. Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Earth minerals (landing site) Organics - Plastic polymers RTV - RCS thruster nozzle cover adhesive Paint and primer				
67	Metallics - Fac. Env./BSM Residue (SRB) Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber - sample cloth Earth minerals (landing site) Organics -RTV(RCS adhesive),Plastic polym Paint and primer				SRB sealant sample: laboratory reference
63	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer		Silica-rich tile(ORB TPS) Hypalon paint (SRB)		

For data on previous missions refer to mission reports prior to STS-59

Figure 8 : Orbiter Post Landing Microchemical Sample Results

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Umbilical	Other
66	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)		
68	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)		ET GOX Vent Seal land area and GOX Seal Sample - Metallic Particulate WINDOW DEBRIS SAMPLE - 'Butcher paper'
64	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer				
65	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-sample cloth Earth minerals (Landing site) Organics-Plastic polymers, SRB sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer		Silica-rich tile (ORB-TPS) Hypalon paint (SRB)		
59	Metallics - Fac.Env./BSM Residue (SRB) RTV, Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Fiber-Building insulation, wipe cloth Earth minerals - (Landing site) Organics- Plastic polymers, sealant RTV(RCS thruster nozzle cover adhesive) Paint and primer				

For data on previous missions refer to mission reports prior to STS-59

Figure 8 continued: Orbiter Post Landing Microchemical Sample Results

10.0 POST LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, six post launch anomalies, but no In-Flight Anomalies (IFA's), were observed on the STS-73 mission.

10.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. No items.

10.2 SOLID ROCKET BOOSTERS

1. A stud hang-up occurred on holddown post #2. As the vehicle gained altitude and the stud became visible above the HDP shoe, aluminum from the wall of the stud hole was observed in the stud threads. Two semi-circular pieces of aluminum fell from the top area of the stud to the HDP shoe. One ordnance fragment fell from the DCS after the stud cleared the stud hole. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe approximately 2 inches before the stud cleared the SRB aft skirt foot.

2. The frustums were missing no TPS. However, the number of debonds (67) over RH frustum fasteners was greater than average. The number of LH frustum MSA-2 debonds over fasteners (54) and over acreage (2) was also greater than average.

10.3 EXTERNAL TANK

1. An 8-inch by 6-inch by 1-inch TPS closeout over the -Y longeron-to-vertical strut/cable tray attach point popped off the External Tank and moved in the -Y direction shortly after ET separation. A large void, but no substrate or primer, was visible afterwards. A cryopumped void in the closeout, along with possible cracks in the TPS closeout induced by flexing of the strut during separation, is believed to be the cause of this event.

2. The LO2 ET/ORB umbilical sustained TPS damage at the top and inboard forward corner. Pieces of loose foam from these damaged areas were wedged against the aft side of the crossbeam. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. Lightning contact strips across the forward part of the umbilical and at the 8 o'clock position were missing. Loss of lightning contact strips was the subject of a previous IFA.

10.4 ORBITER

1. The Orbiter lower surface sustained a total of 102 hits, of which 17 had a major dimension of 1-inch or larger. The largest lower surface tile damage site occurred approximately 10 feet forward of the RH MLG wheel well and measured 11.0 inches long by 3.8 inches wide by 0.8 inch maximum depth. The site showed significant signs of re-entry heating including interior glazing, slumping at the tile edge, and melting of the surface coating material.

2. Numerous damaged clips on the EO-2 and EO-3 "salad bowl" liners were noted: (EO-2: two bent, two missing; EO-3: two bent, six missing).

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

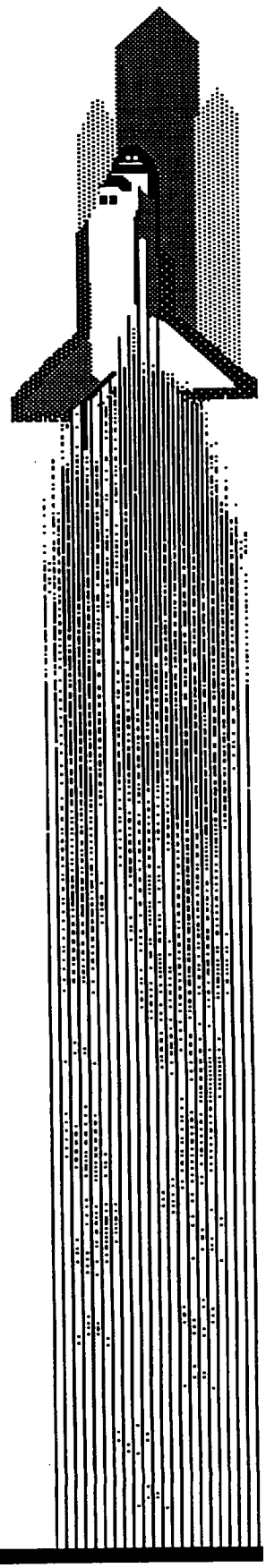
Space Shuttle

Earth Science Branch

Image Science and
Analysis Group

STS-73 Summary of Significant Events

December 5, 1995



Space Shuttle Image Science and Analysis Group

STS-73 Summary of Significant Events

Project Work Order - SN-5CR

Approved By

Lockheed Martin

J. M. Disler 12-5-95
J. M. Disler, Project Analyst
Image Science and Analysis Group

M. H. Trenchard 12/5/95
M. H. Trenchard, Project Manager
Image Analysis Projects

Jess G. Carnes
Jess G. Carnes, Operations Manager
Basic and Applied Research Department

NASA

C. Diane McLaughlin
C. Diane McLaughlin, Lead
Image Science and Analysis Group
Earth Science Branch

Prepared By

Lockheed Martin Engineering and Sciences Company
for
Earth Science Branch
Earth Sciences and Solar System Exploration Division
Space and Life Sciences Directorate

Table of Contents

Table of Contents

1. STS-73 (OV-102): FILM / VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-73 launch of Columbia (OV-102) from pad B occurred on Friday, October 20, 1995 (day 293) at 13:53:00.021 Coordinated Universal Time (UTC) as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 13:55:03.593 UTC as seen on camera ET207.

On launch day 24 of 24 expected videos were received and screened. Following launch day, 52 films were screened. Camera film E224 was not received. No potential anomalies were observed during launch.

Detailed Test Objective 312, photography of the external tank after separation, was performed using the Orbiter umbilical well cameras (method 1). The handheld Nikon camera with a 300 mm lens and 2X extender was also used on STS-73 (method 3).

1.1.2 Landing

Columbia landed on runway 33 at KSC on November 5, 1995. Ten videos of the Orbiter's approach and landing were received.

No major anomalies were noted in any of the approach, landing, and roll-out video views screened. The drag chute deployment appeared normal.

1.2 TIMING ACTIVITIES

Launch:

Video cameras: OTV149, ET208, and KTV11 did not have IRIG timing. All other videos had timing.

Film cameras: E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16, E17, E18, E19, E20, E25, E26, E30, E33, E34, E35, E36, E40, E50, E52, E54, E57, E59, E60, E62, E63, E65, E76, E77, E79, and E222, had in-frame alphanumeric timing. The time codes from videos and films were used to identify specific events during the initial screening process.

Landing:
Ten videos were screened on landing day. Seven videos: EL18IR, KTV11L, KTV13L, KTV15L, KTV33L, KTV5L, and SLF South had timing. There was no IRIG timing for videos SLF North, KTV20L and EL17IR.

Event Description	Time (UTC)	Camera
Landing gear - doors opened	309:11:45:03.145	KTV33L
Touchdown		
Left Main Wheel	309:11:45:20.797	SLF-South
Right Main Wheel	309:11:45:20.914	SLF-South
Drag Chute Initiation	309:11:45:29.122	SLF South
Pilot Chute at Full Inflation	309:11:45:30.120	KTV-11
Bag Release	309:11:45:30.687	KTV-11
Drag Chute Inflation in Reefed Configuration	309:11:45:31.588	KTV-11
Nose Wheel	309:11:45:35.193	KTV33L
Drag Chute Inflation in Disreefed Configuration	309:11:45:35.208	KTV-11
Drag Chute Release	309:11:45:57.981	KTV-11
Wheel stop	309:11:46:15.920	KTV15L

Table 1.2.2: Landing Video Timing Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

2.1.1 Debris Near the Time of SSME Ignition

2.1.1.1 Debris at T-4 seconds
(Camera: E16)

Several flat rectangular pieces of debris (probably RCS paper) were seen between the SSMEs and the body flap prior to SRB ignition at T-4 seconds.

2.1.1.2 Debris at T-3 seconds
(Camera: E2)

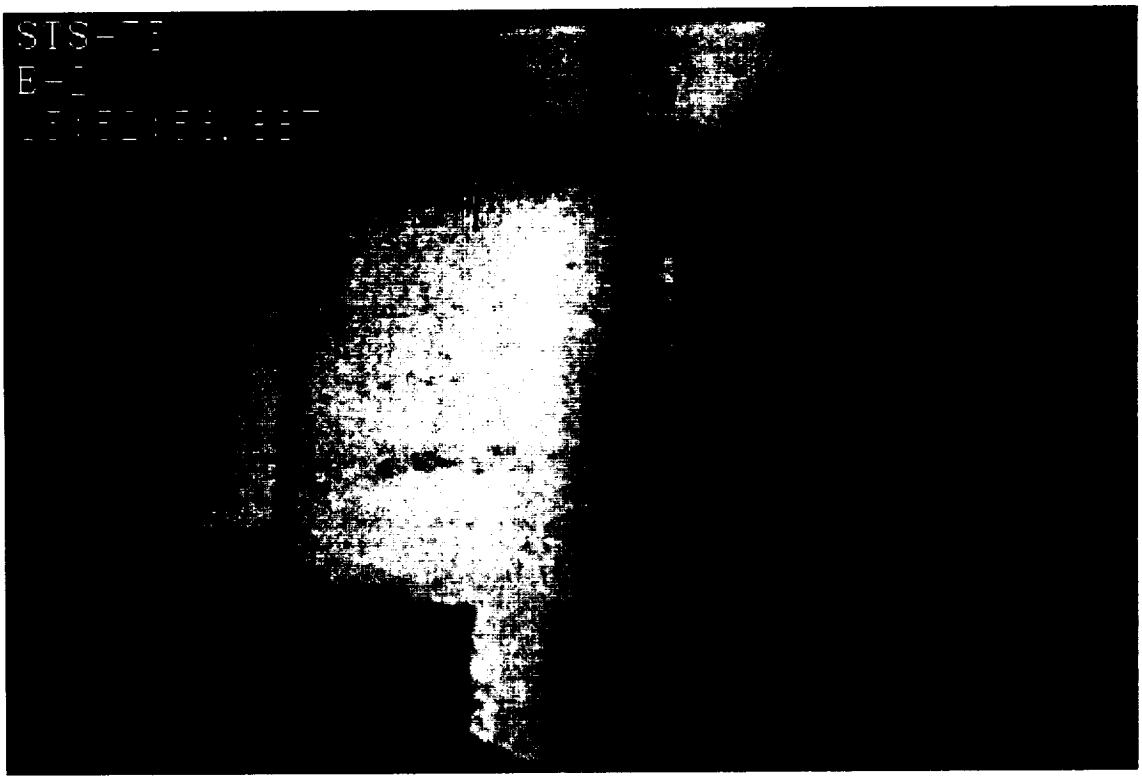


Figure 2.1.1.2 Dark Piece of Debris at SSME Ignition

A single dark piece of debris traveled through the field of view from left to right in front of the right OMS pod and the LO2 TSM at SSME ignition. The debris was not seen to strike the vehicle.

2.1.1.3 LH2 and LO2 ET/Orbiter Umbilical Disconnect Debris
(Cameras: OTV109, OTV154, OTV163, E1, E4, E5, E6, E16, E31, E34, E36, E40, E41, E52)

Normal ice debris was noted falling from the LH2 and LO2 ET/Orbiter umbilical disconnect areas at SSME ignition through liftoff. No follow-up action was requested.

2.1.2 Debris Near the Time of SRB Ignition

2.1.2.1 SRB Flame Duct Debris

(Cameras: E1, E3, E7, E8, E9, E10, E11, E12, E13, E14, E15, E60, E63, E77)

As on previous missions, debris was noted originating from the SRB flame duct area after SRB ignition. No Follow-up action was requested. Three pieces of debris, one large and rectangular, were seen on the right side of the field of view near the LSRB holddown post M-7 at 0.5 seconds MET. A single dark colored piece of debris first seen below the LSRB holddown post M-6 DCS fell aft into the SRB flame trough at 0.7 seconds MET. Three small rectangular pieces of debris (possibly close-out tags) were seen between LSRB holddown posts M-7 and M-8 at 0.5 seconds MET.

Figure 2.1.2.1 Two Pieces of Debris Between LSRB Holddown Posts M-7 and M-8

Two pieces of debris, one small and dark, one large and rectangular (possibly cardboard), were seen on the left side of the view between LSRB holddown posts M-7 and M-8 at 0.7 seconds MET. Multiple pieces of red water baffle material were seen passing through the field of view at SRB ignition (camera E14).

2.1.2.2 LH2 and LO2 Tail Service Mast (TSM) T- 0 Umbilical Disconnect Debris
(Cameras: OTV150, E17, E18, E19, E20, E31, E63, E76, E77)

Normal ice debris was noted falling from the LH2 and LO2 TSM T-0 umbilical disconnect areas at liftoff. None of the debris was observed to strike the vehicle. No follow-up action was requested.

2.1.2.3 GH2 Vent Arm Debris During Disconnect and Retraction
(Cameras: E33, E34, E35, E50, E54, E59, E60)

Vapor and multiple light colored pieces of ice debris fell from the GH2 vent arm carrier plate at vent arm retraction. The GH2 vent arm appeared to retract normally.

2.1.2.4 Debris at Liftoff
(Cameras: E31, E79)

A single light colored piece of debris (origin unknown) fell from the top of the view between the Orbiter and ET and fell in front of the LH2 umbilical at liftoff (E31). A small light colored piece of debris was seen falling along the ET LO2 feedline at liftoff (E79). The debris was not seen to contact the vehicle. No follow-up action was requested.

2.1.3 Debris After Liftoff
(Cameras: E76, E207, E212, E222)

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) at liftoff, throughout the roll maneuver and beyond on the launch tracking views. The debris was probably reaction control system (RCS) paper and ice from the ET/Orbiter umbilicals. Debris of this type was seen at 1, 13.4, 17.1, 19.8, 21.8, 30.6, 31.6, and 38.2 seconds MET. None of the debris was seen to contact the launch vehicle. No follow-up action was requested.

2.1.3.1 Debris from 6 to 12 seconds MET
(Cameras: E52, E223)

Multiple pieces of white debris (probably umbilical ice) were seen falling along the flap from 6 to 12 seconds MET.

2.1.3.2 Debris at 12.3 seconds MET
(Camera: E57)

A single piece of light colored debris was seen falling aft of the left aft ET/Orbiter attach strut at 12.3 seconds MET.

2.1.3.3 Debris from 18.7 to 22.8 seconds MET
(Camera: E59)

After the roll maneuver six small light colored pieces of debris were seen emerging from the LSRB exhaust plume from 18.7 to 22.8 seconds MET.

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.2.1 Orange Colored Stains/Streaks on LSRB
(Camera: E33)

Orange colored stains/streaks were seen on the LSRB just forward of the aft ET attach ring. No follow-up action was requested.

2.2.2 Flicker of Light Near LH2 TSM T-0 Umbilical
(Camera: E76)

A flicker of light or possibly a reflection was noted near the opening of the LH2 TSM T-0 umbilical door at approximately T-5 seconds. No follow-up action was requested.

2.2.3 White Vapor from ET LH2/Intertank Interface Vent
(Camera: E34)

White vapor was seen coming from the ET LH2/Intertank interface vent at T-0.4 seconds. This event has been seen on previous missions. No follow-up action was requested.

2.2.4 Bolt Hang-up on RSRB Holddown Post M-2
(Camera: E8)

Figure 2.2.4 Bolt Hang-up on RSRB Holddown Post M-2

A bolt hang-up was seen on the RSRB holddown post M-2 at 13:53:00.665 UTC. The bolt released from the RSRB and retracted to its normal position after extending approximately nine inches above the shoe. At the same time, a single crescent shaped, light colored, shiny piece of debris appeared to originate from the DCS hole and fell into the flame duct. Rockwell Downey engineers had previously reported the possibility that one of the holddown bolts had hung-up based on the accelerometer data prior to the receipt of the films at JSC. The event was reported to the Mission Evaluation Room (MER) manager and the Shuttle Mission Management Team (MMT). No follow-up action was requested.

Table 2.2.4 lists the SRB holddown post bolt hang-ups seen on previous missions.

MISSION	LOCATION OF HANG-UP
STS-34	RSRB holddown post M-2
STS-33	RSRB holddown post M-3
STS-39	RSRB holddown post M-1
STS-43	LSRB holddown post M-7
STS-45	RSRB holddown post M-4
STS-50	RSRB holddown post M-4
STS-46	LSRB holddown post M-7
STS-53	RSRB holddown post M-1

Table 2.2.4 SRB Holddown Post Bolt Hang-Ups Seen on Previous Missions

2.2.5 Orange Vapor
(Cameras: E36)

Orange vapor (possibly free burning hydrogen) was seen under the body flap during SSME ignition. Orange vapor has been seen on previous missions. No follow-up action was requested.

2.2.6 SSME Mach Diamonds Formed Out of Sequence
(Cameras: OTV170, E19, E20, E76)

The SSME Mach diamond on SSME #2 formed slightly before the Mach diamond for SSME #3. Normally Mach diamonds form in the sequence SSME #3, SSME #2, and SSME #1. Variations in the sequence of Mach diamond formation were seen on missions STS-71 and STS-59.

STS-73 Mach Diamond Formation Times:
293:13:52:56.858 UTC - Mach diamond formation noted SSME #2
293:13:52:56.979 UTC - Mach diamond formation noted SSME #3
293:13:52:56.999 UTC - Mach diamond formation noted SSME #1

2.2.7 Base Heat Shield Erosion
(Cameras: E17, E18, E19)

Small Areas of TPS erosion were noted on both the left and right sides of the base heat shield and on both RCS stingers. Heat shield erosion has been seen on previous missions. No follow-up action was requested.

2.2.8 RSRB HPU Venting
(Camera: E222)

Intermittent white puffs of vapor were visible coming from the LSRB Hydraulic Power Unit (HPU) exhaust port prior to SSME ignition. This event has been seen on previous mission films. No follow-up action was requested.

2.3 ASCENT EVENTS

2.3.1 Body Flap Motion
(Cameras: E207)

Body flap motion was visible from 23 to 49.4 seconds MET. Body flap motion calculations are no longer being performed unless there is a special request.

2.3.2 Flares in SSME Exhaust Plume
(Camera: E222)

A flare (probably due to debris) was noted in the SSME exhaust plume at 25 seconds MET. A second flare was seen in the SSME exhaust plume at 35.3 seconds MET. Flares in the SSME exhaust plumes have been seen on previous mission launch films. No follow-up action was requested.

2.3.3 White Flashes in SSME Exhaust Plume
(Camera: E52, E222)

White flashes (seen on previous missions) were noted along the SSME exhaust plume during the roll maneuver from 8 to 21 seconds MET. No follow-up action was requested.

2.3.4 Puff in SSME Exhaust Plume
(Camera: E222)

A white vaporous puff (possibly caused by debris) was noted in the SSME exhaust plume at 38.9 seconds MET. No follow-up action was requested.

2.3.5 Condensation
(Cameras: E205, E212, E213, E218, E220, E222, E223)

A white condensation cloud was seen around the Shuttle Launch Vehicle between 32 and 49 seconds MET. A condensation cloud around the Shuttle Launch Vehicle near the point of maximum dynamic pressure has been seen on previous missions. No follow-up action was requested.

2.4 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (DTO-312)

2.4.1 Analysis of the STS-73 Handheld External Tank Pictures (Task #5)

DTO-312 handheld photography of the STS-73 external tank (after separation) was acquired with a Nikon camera with a 300 mm lens and a 2X extender (Method 3). The pitch maneuver for photographing the external tank was performed on STS-73.

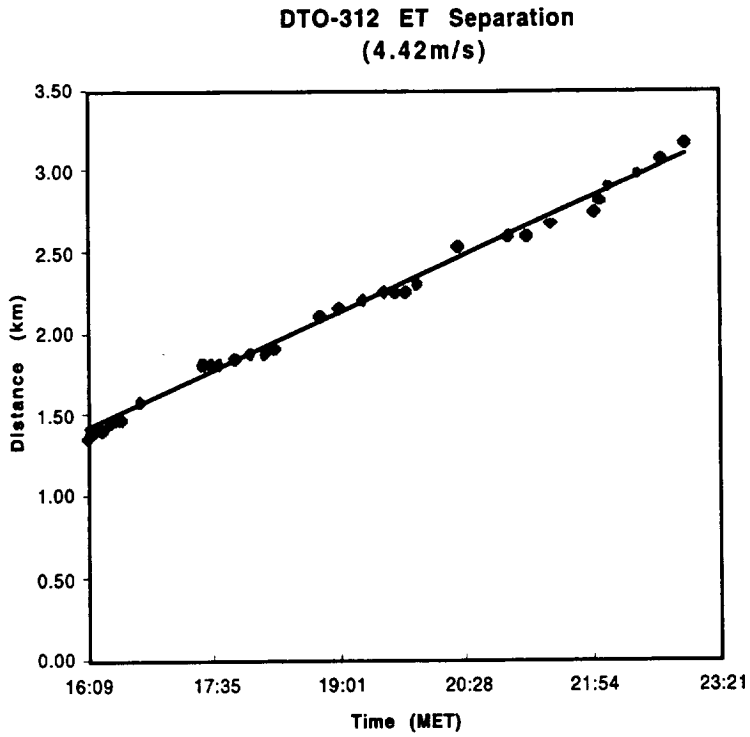


Figure 2.4.1 (A) ET Separation Velocity

The external tank was calculated to be a distance of 1.37 kilometers away from the Orbiter on the first image (taken 16 minutes after liftoff). The tank separation velocity was calculated to be 4.42m/s. The roll rate of the external tank was calculated to be 0.15 deg/sec. The tumble rate was calculated to be 1.91 deg/sec.

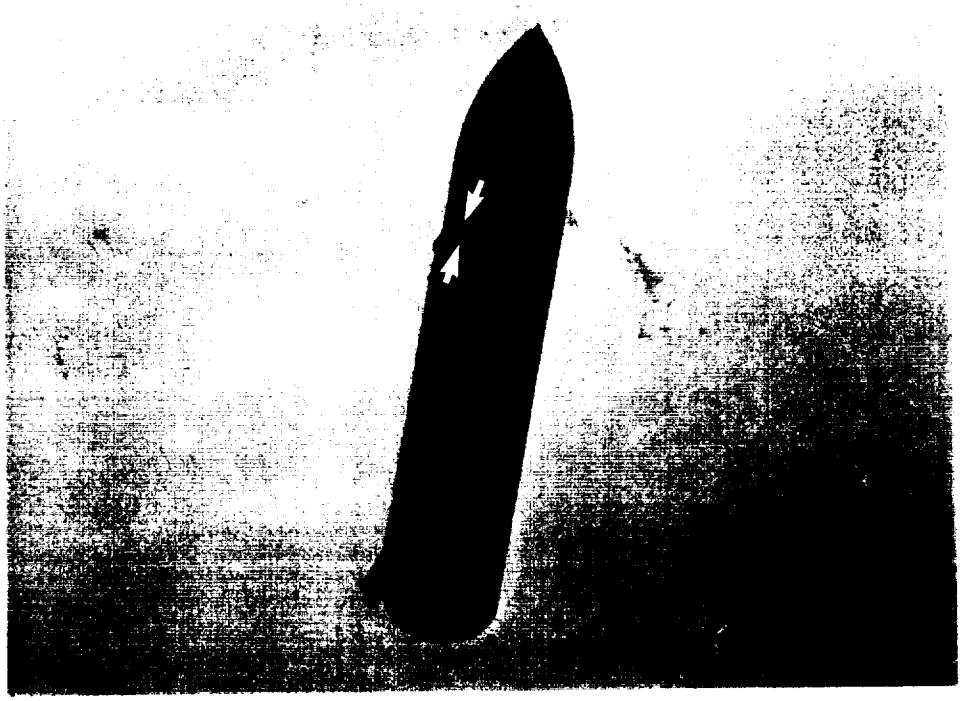


Figure 2.4.1 (B) Light Colored Marks on the +Y Axis of ET Intertank

Light colored marks were noted on the +Y axis of the Intertank in the BSM burn scar near the RSRB/ET forward attach point. Similar marks were seen near the LSRB/ET forward attach on the STS-57 handheld ET photography.

2.4.2 Analysis of the Umbilical Well Camera Films (Task #5)

Three rolls of STS-73 umbilical well camera film were acquired: the 35 mm film from the LO2 umbilical and two 16 mm films (5 mm lens and 10 mm lens) from the LH2 umbilical. The +X translation maneuver was not performed on STS-73. (Note: The 35 mm LO2 umbilical film ended prior to the imaging of the ET intertank. Not imaging the ET intertank is a result of not performing the +X translation maneuver and the film cutting short after 44 frames instead of the planned 60 frames).

The following items were seen on the umbilical well films:

35 mm LO2 Umbilical Film Screening:

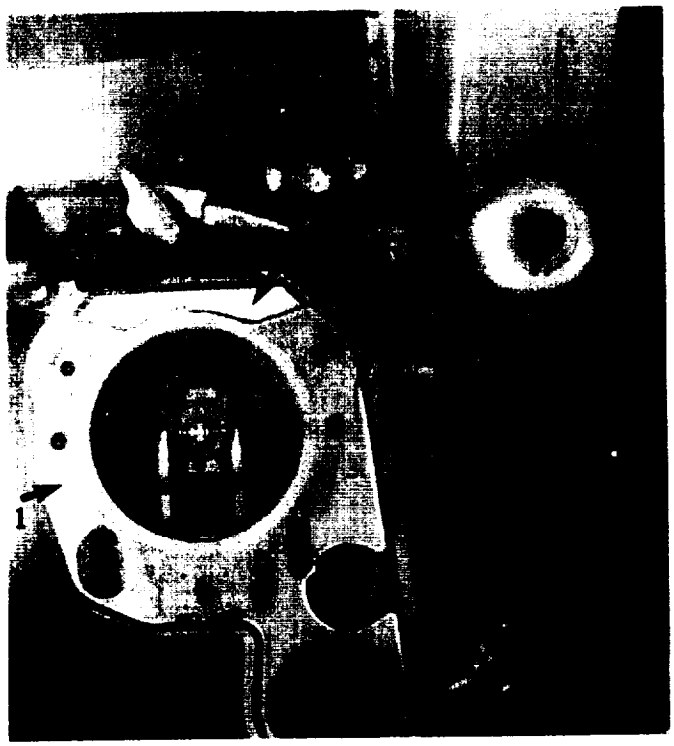


Figure 2.4.2 (A) LO2 Umbilical Events

Two lightning contact strips at the 8 o'clock (1) and 12 o'clock (2) positions near the LO2 17 inch flapper valve were missing. LO2 umbilical lightning contact strip(s) were noted to be missing on STS-57, STS-58, STS-65, STS-66, STS-71, STS-69 and other previous mission umbilical well films. Missing lightning contact strips were covered on a previous IFA.

TPS damage was noted at the top inboard forward corner of the LO2 umbilical (3). A piece of light colored material (possibly foam) was seen just forward of the LO2 umbilical just aft of the crossbeam (4). Numerous areas of TPS erosion were visible on the horizontal and vertical sections of the LO2 cable tray (5).

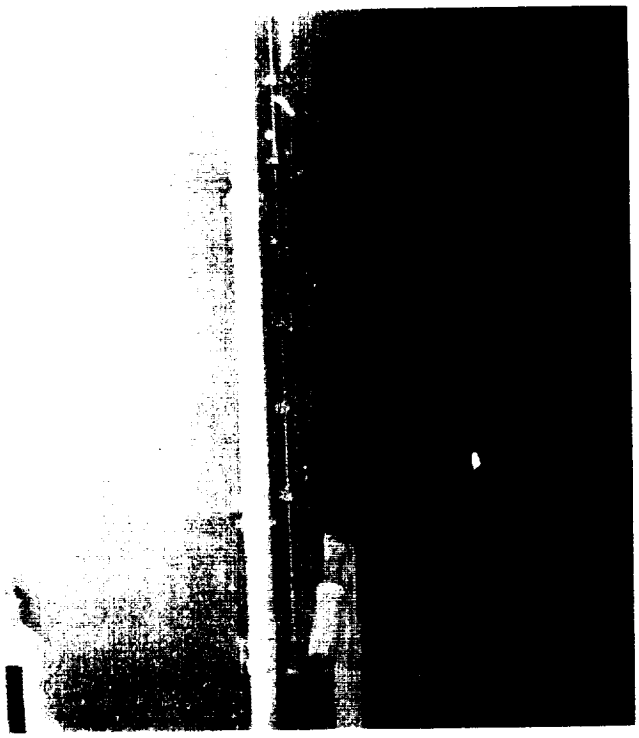


Figure 2.4.2 (B) Divots on ET LH2 Tank Acreage

Shallow divots on the ET LH2 tank acreage outboard of the LH2 cable tray were noted (1). The debris object (2) may be a missing lightning contact strip from the LO2 umbilical.

Multiple small white debris objects are visible through out the film sequence. These white debris objects appear to be frozen hydrogen.

16 mm LH2 Umbilical Well Film Screening (5 mm & 10 mm Lens):

Numerous light colored pieces of debris (probably insulation) are in view throughout the SRB film sequence. Typical chipping and erosion of the electric cable tray are visible. Multiple pieces of white debris (frozen hydrogen) were visible throughout the ET separation sequence. These events are typical of those seen on previous mission umbilical well camera views.

Figure 2.4.2 (C) Metallic Appearing Debris

A metallic appearing debris object is visible on the 16mm film (10mm lens frame 8303) approximately 14 seconds after ET separation. This debris is believed to be a missing lightning contact strip from the LO2 umbilical.

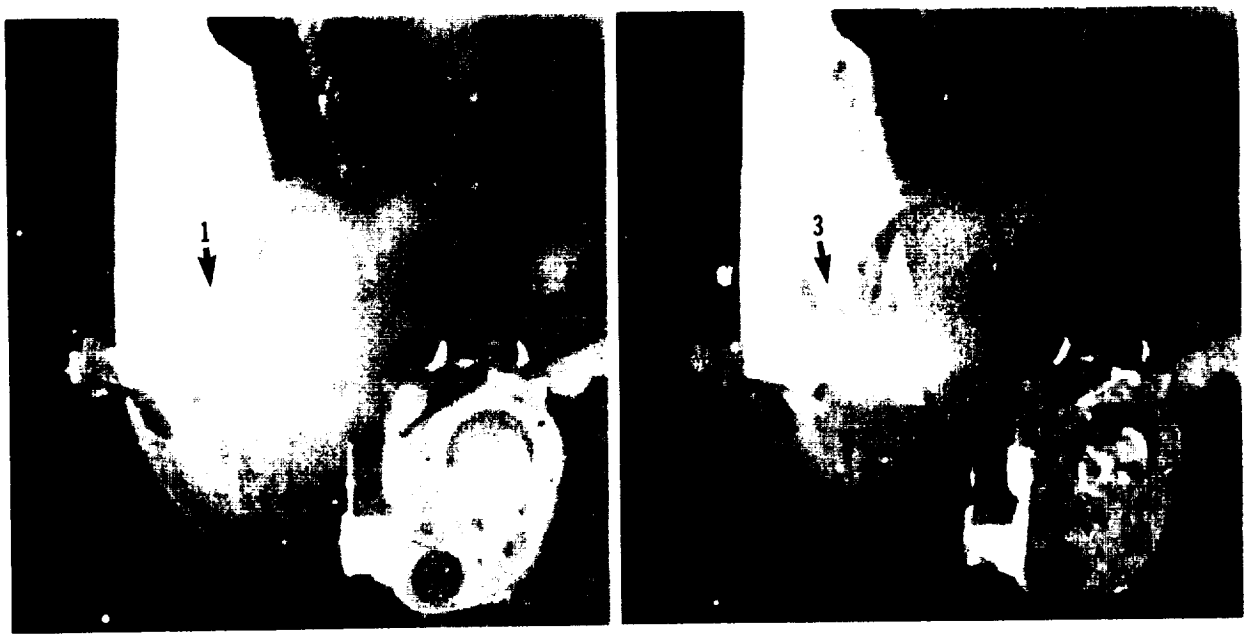


Figure 2.4.2 (D) Detached Closeout on the -Y Longeron-to-Vertical Strut Attach Point

A piece of closeout on the -Y longeron-to-vertical strut/cable tray attach point was seen to detach approximately five seconds after ET separation. The view on the left shows the closeout prior to detachment (1). The view on the right shows the detached TPS (2) and the resulting divot (3). No substrate was visible in the resulting divot.

A small, reflective, rectangular object was seen coming from behind the umbilical cable tray approximately twenty seconds after ET separation (5mm film, frame 6558). The origin of this object was not determined.

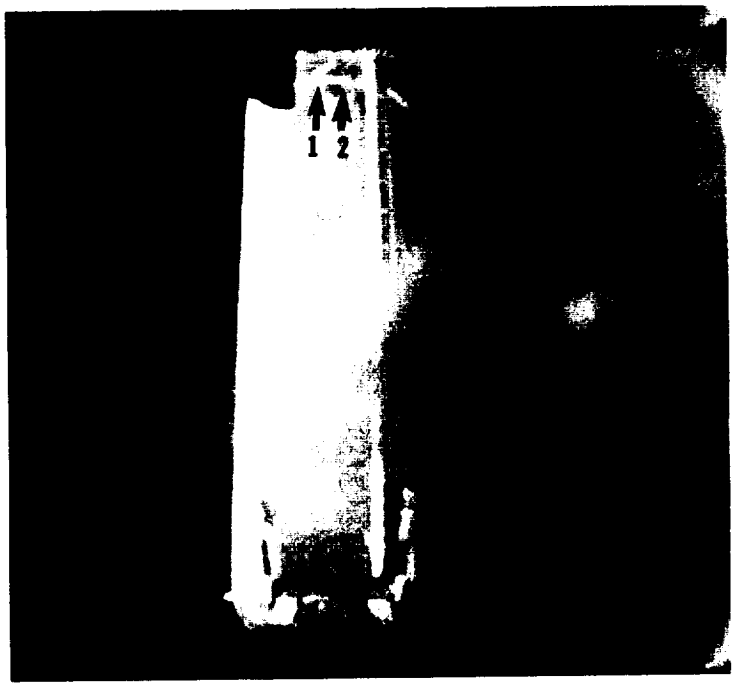


Figure 2.4.2 (E) Forward ET/Orbiter Attach Bipod Jack Pad Closeouts

A white mark is visible on the LH2 tank/intertank closeout flange under the left leg of the forward ET/Orbiter attach bipod (1). A second smaller white mark is visible near the right leg bipod on the same flange (2). These white marks were determined by KSC to be the pre-launch jack pad closeouts. Comparison of the umbilical well photography and pre-launch closeout photography of the jack-pads showed that the jack-pad closeouts were undamaged.

2.5 LANDING EVENTS

2.5.1 Landing Sink Rate Analysis (Task #3)

The main gear sink rate of the Orbiter was determined over a one second time period prior to main gear touchdown. Also, the nose gear sink rate was determined over a one second time period prior to the nose gear touchdown.

The measured main gear and nose gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle (the landing weight of the STS-73 Orbiter was reported to be 230,416 lbs.). The sink rate measurements for STS-73 are given in Table 2.5.1. In Figures 2.5.1 (A) and 2.5.1 (B) the trend of the measured data points for video image data are illustrated.

Prior to Touchdown (1 sec)	Sink Rate: Video
Main Gear	2.7 ft/sec
Nose Gear	3.83 ft/sec

Table 2.5.1: Sink Rate Measurements

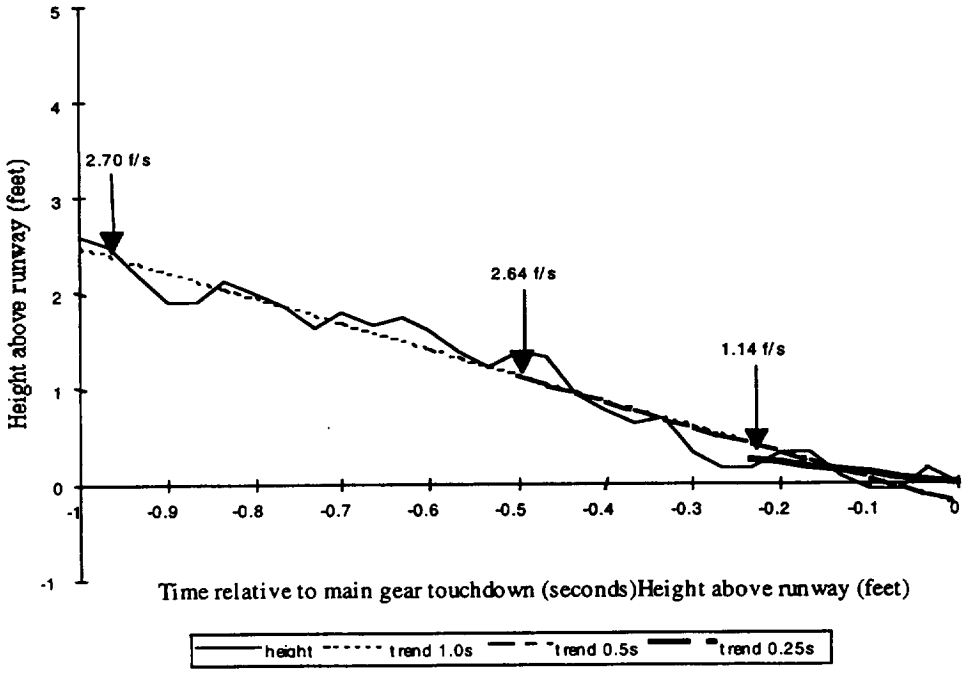


Figure 2.5.1 (A) Main Gear Height Versus Time Prior to Touchdown (Video)

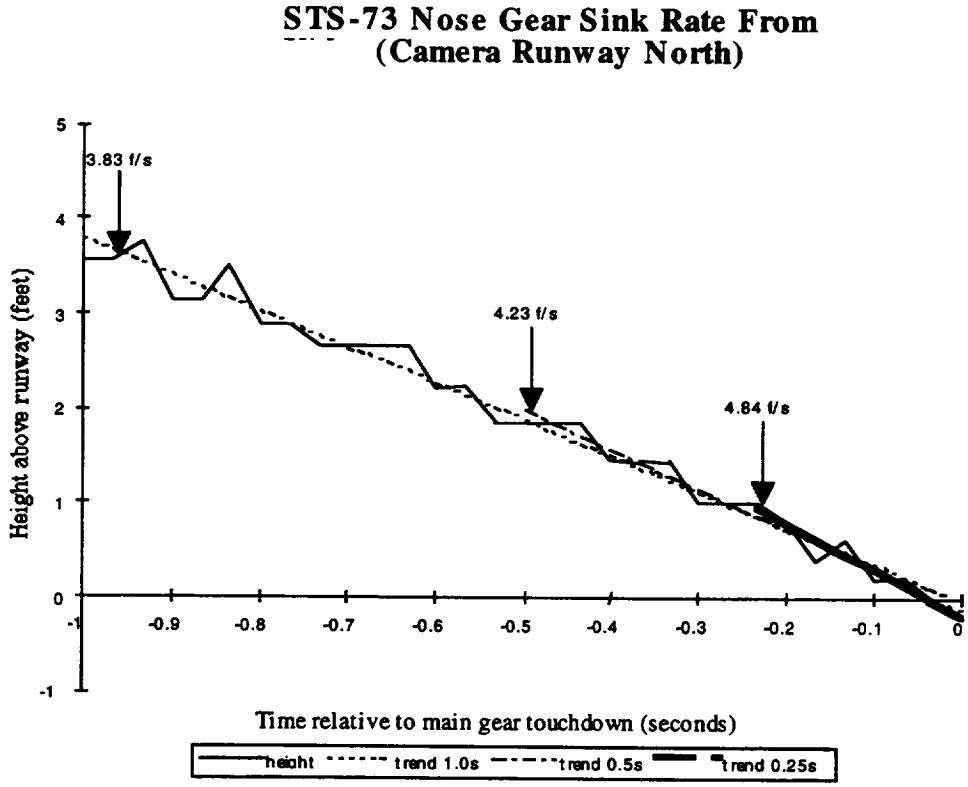


Figure 2.5.1 (B) Nose Gear Height Versus Time During Rollout (Video)

2.6 OTHER

2.6.1 Normal Events

Other normal events observed include: inboard elevon motion at SSME ignition, RCS paper debris at SSME ignition, ET twang, multiple pieces of light colored debris falling from the LH2 and LO2 TSM T-0 umbilicals at disconnect, vapor and ice from the GUCP area during ET GH2 vent arm retraction, acoustic waves in the exhaust cloud at liftoff, vapor off the SRB stiffener rings after liftoff, outguessing of the ET aft dome, roll maneuver, forward RCS paper detaching after the roll maneuver, expansion waves after the roll maneuver, recirculation, SRB plume brightening prior to SRB separation, SRB separation, linear optical effects before and after SRB separation, multiple light colored debris in the SRB exhaust plume after separation.

Normal events seen that are related to the pad are hydrogen ignitor operation, fixed service structure (FSS) deluge water activation, GH2 vent arm retraction, sound suppression water initiation, mobile launch platform (MLP) water dump activation, TSM door closure at liftoff.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

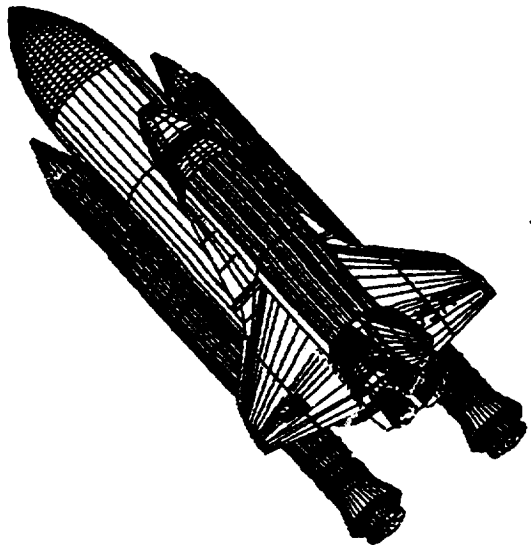
National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SPACE SHUTTLE

ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-73



ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

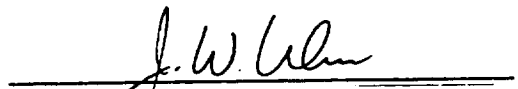
STS-73

FINAL

PREPARED BY:

B. EPPS, J. HIXSON
PHOTOGRAPHIC ANALYSIS/ROCKWELL/HSV

SUBMITTED BY:



J.W. ULM
WBS MANAGER, PERFORMANCE ANALYSIS/ROCKWELL/HSV

APPROVED BY:

T. RIECKHOFF, MSFC/EP42
B. LINDLEY-ANDERSON, MSFC/EP42

STS-73 ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

TABLE OF CONTENTS

November 27, 1995

I. INTRODUCTION:

The launch of space shuttle mission STS-73, the eighteenth flight of the orbiter Columbia, occurred on October 20, 1995, at approximately 8:53 A.M. Central Daylight Time from launch complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Launch time was reported as 95:293:13:53:00.013 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team. Extensive photographic and video coverage exists and was evaluated to determine proper operation of the ground and flight hardware. Cameras (video and cine) providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, onboard the vehicle, and uprange and downrange tracking sites.

II. ENGINEERING ANALYSIS OBJECTIVES:

The planned engineering photographic and video analysis objectives for STS-73 include, but were not limited to the following:

a. Overall propulsion system coverage for anomaly detection and structural integrity
b. Determination of SRB PIC firing time and SRB separation time
c. Verification of Thermal Protection System (TPS) integrity
d. Correct operation of the following:

    1. SSME ignition
    2. SRB debris containment system
    3. LH2 and LO2 17-inch disconnects
    4. Ground umbilical carrier plate (GUCP)
    5. Free hydrogen ignitors
    6. Booster separation motors (BSM)
    7. Vehicle clearances
    8. Vehicle motion

e. Verification of cameras, lighting and timing systems

III. CAMERA COVERAGE ASSESSMENT:

Film was received from fifty-two of fifty-three request cameras and video from twenty-five requested cameras. The following table illustrates the camera coverage received to date at MSFC for STS-73.

Camera Data Received at MSFC for STS-73

	16mm	35mm	Video
MLP	22	0	4
FSS	7	0	3
Perimeter	3	3	6
Tracking	0	14	12
Onboard	2	1	0
Totals	34	18	25

Total number of films and videos received to date: 77

a. Ground Camera Coverage:

Tracking data from several cameras was sporadic due to the cloud coverage. All ground base cameras operated properly except for item E224 which experienced a film magazine jam.

b. Onboard Camera Coverage

The orbiter Columbia carried two 16mm motion picture cameras in the LH2 umbilical well to record the SRB and ET separation events. A 35mm sequential still camera was flown in the LO2 umbilical well to record the ET after separation.

IV. ANOMALIES:

The holddown post M-2 stud hung-up in the aft skirt at liftoff. Measured motion data of the post components are shown in figure 1. Figure 2 is a film frame from camera E-8 showing the stud hang up and the location of the measured components. The holddown post shoe was lifted up approximately 2 inches during liftoff. The stud appeared to remain fully extended until the aft skirt cleared the top of the stud.

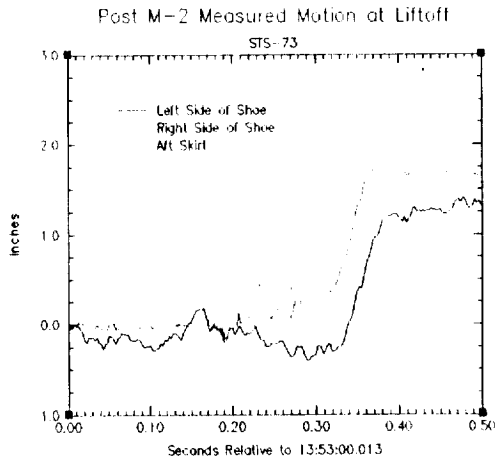


Figure 1. Measured Motion Data

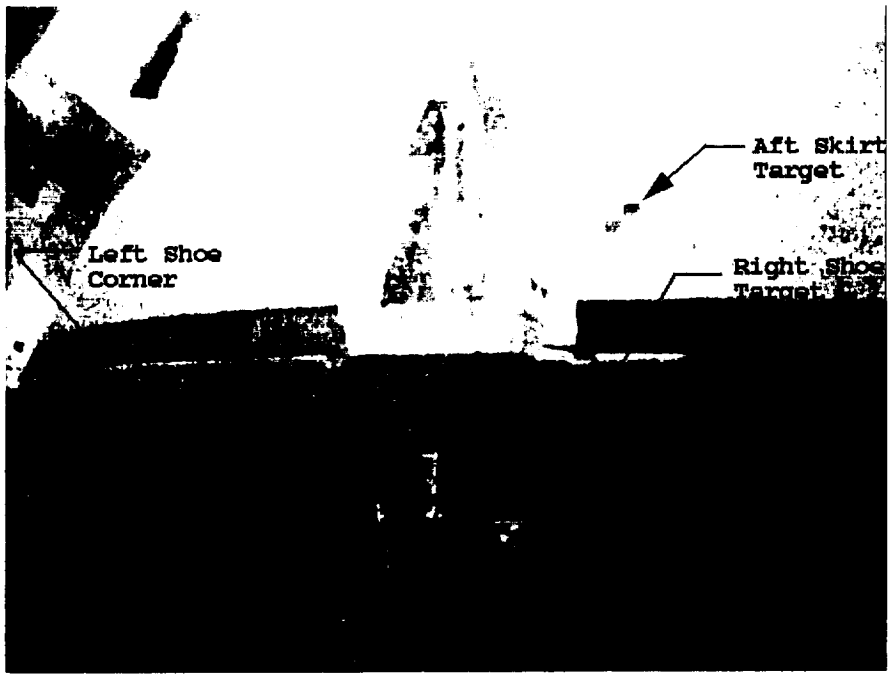


Figure 2. Post M-2 Stud Hang-up

V. OBSERVATIONS:

The SSME #3 mach diamond formed late during the start sequence. All other start events appeared to occur normally on this engine. The late mach diamond formation is believed to be a function of the ambient base pressure.

Several pieces of debris were blown from the left SRB blast hole during motor ignition between posts M-6 and M-8. One debris object appears to be a piece of cardboard. None of these debris objects struck the vehicle but were aspirated into the secondary blast holes.

White vapors were observed being vented from the +Z aero vent in the ET intertank during SSME thrust buildup and at liftoff. This venting is shown in figure 3. This type of venting has been observed on previous flights (STS-51 & STS-70).

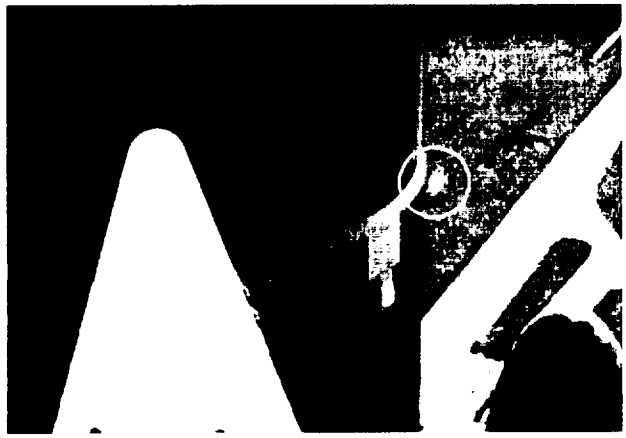


Figure 3. White Vapors Venting From Intertank

Typical events during ascent were observed. These include butcher paper debris, debris induced streaks in the SSME plume, glowing debris being ejected from the SRM plume, and flow recirculation.

VI. ENGINEERING DATA RESULTS:

a. T-Zero Times:

T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

Holddown Post	Camera Position	Time (UTC)
M-1	E-9	13:53:00.021
M-2	E-8	13:53:00.023
M-5	E-12	13:53:00.022
M-6	E-13	13:53:00.023

b. SRB Separation Time:

Best estimate of the SRB separation time for STS-73 is 293:13:55:03.64 UTC as recorded by camera E-212.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1995	Final 26 Sept - 6 November 1995

4. TITLE AND SUBTITLE
Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-73

5. FUNDING NUMBERS
OMRS00U0

6. AUTHOR(S)
Gregory N. Katnik
Barry C. Bowen
Jill D. Lin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
John F. Kennedy Space Center, NASA
Vehicle Engineering/Mechanical Systems Division
ET/SRB Branch TV-MSD-7
Kennedy Space Center, Florida 32899

8. PERFORMING ORGANIZATION REPORT NUMBER
TM 111465

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Blanket Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-73. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanner data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in flight anomalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Shuttle Mission STS-73 and the resulting effect on the Space Shuttle Program.

14. SUBJECT TERMS
SUBJECT CATEGORY: 15, 16
STS-73 Thermal Protection System (TPS)
Ice Debris Photographic Analysis

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTR/
Unclassified	Unclassified	Unclassified	Unlimited

KSC DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS
REPORT DISTRIBUTION LIST 9/95

NASA - KSC

MK/L. J. Shriver
TE-COM-2/C. Brown
TV-PEO-2/R. Harrison
TV-MSD/C. Stevenson
TV-MSD-7/G. Katnik (7)
RO-SLQ-3/J. L. Shehane
GK-5/Z. H. Byrns
SK-LOS/J. Martin
LSO-321/H. L. Lamberth
LSO-437/M. Valdivia
ZK-88/K. J. Mayer
BICO-RVITS/R. B. Hoover
MMC-15/D. S. Otto
USBI-LSS/L. Clark

NASA - HQ

QSO/W. Comer

NASA - JSC

EP2/B. Rosenbaum
ES3/J. Kowal
FA22/D. Camp
SN3/E. Christiansen
SN5/M. Gaunce

Johnson Space Center
Houston, Texas 77058

NASA - MSFC

ED31/D. Andrews
EE31/M. A. Pessin
EE31/C. A. Snoddy
EP24/T. J. Rieckhoff

Marshall Space Flight Center
Huntsville, AL 35812

Rockwell - Downey

AE21/J. McClymonds
FA44/R. Ramon

Rockwell International
12214 Lakewood Blvd
Downey, CA 90241

Martin Marietta

Dept. 3571/S. Copsey
Dept. 4200/P. Lewis

13800 Old Gentilly Road
New Orleans, Louisiana 70129

P. O. Box 29304
New Orleans, Louisiana 70189